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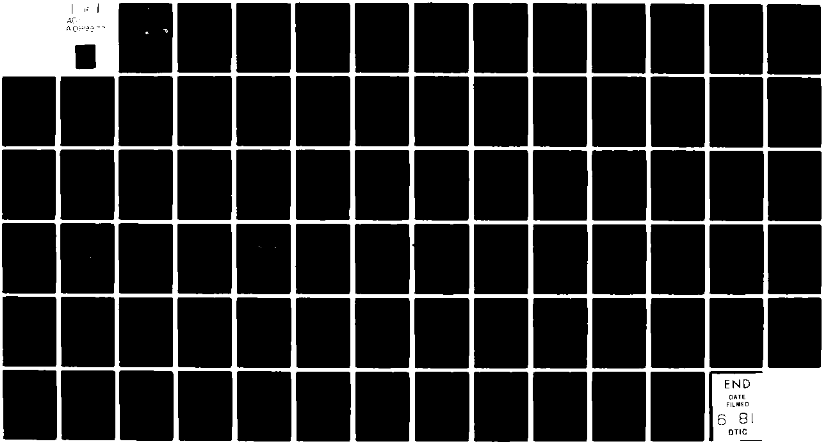

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Diane L. Damos and Thomas E. Smist

November 1980

NAVAL BIODYNAMICS LABORATORY
New Orleans, Louisiana

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INDIVIDUAL DIFFERENCES IN DUAL-TASK PERFORMANCE

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Eleven right-handed males participated in an experiment examining individual differences in multiple-task performance. Three task combinations were used in the study. The first was composed of a memory task and a classification task. The second consisted of two identical

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one-dimensional compensatory tracking tasks. The third was a dichotic listening task. On Day 1 of the experiment the subjects practiced each task alone. On Days 2, 3, and 4 they performed primarily under dual-task conditions. However, periodically dual-task practice was interrupted to reassess single-task performance.

All dual-task data were analyzed first to determine when stability occurred. Each subject's stabilized data from the tracking-tracking and memory-classification combinations then were corrected for the appropriate single-task baseline. Finally, the subjects were grouped according to which of three response strategies they used to perform the memory-classification task combination. These strategies were a massed strategy (in which the subject would emitt a series of responses to one task before responding to the other), an alternating response strategy, and a simultaneous response strategy. A two-way repeated measures MANOVA conducted on the stablized adjusted data indicated both a significant effect of trials and groups. Possible sources of the between-group differences are discussed.

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INTRODUCTION

With recent advances in technology the operator's role in many man-machine systems has changed from that of a direct controller to that of a monitor, information processor, and decision maker. As such, the human being is frequently called on to perform two or more tasks concurrently. Operators for such systems usually have been selected on the basis of their performance on one or more of the component tasks or on their scores on tasks which are known to correlate with performance on the component tasks. Rarely has any attempt been made to select candidates on the basis of their concurrent-task performance.

This failure may be attributed in part to the lack of experimental evidence for a general timesharing ability. This is particularly striking in view of the widely held belief of training personnel that such an ability exists. Indeed, it is not unusual when talking to instructor pilots to hear a remark that a certain student is a poor pilot not because he cannot perform each of the tasks alone but because he cannot timeshare them.

The lack of experimental evidence for a general timesharing ability does not imply, however, that individuals do not differ in some consistent fashion on various task combinations; it simply implies that no group of individuals is consistently better across all task combinations than another group. It is perfectly conceivable that some individuals perform well on certain types of combinations while others perform well on other types. Any number of individual characteristics could be the basis for between-group differences in multiple-task performance. The most obvious of these are sex, age, handedness, degree of cerebral specialization, intelligence, and multi-limb coordination. It is equally likely that task variables--such as input and output modality--could be the basis for between-group differences. For example, some people might perform better when both inputs are in the same modality while others perform better when the inputs are in different modalities.

The experiment presented in this paper addresses the question of individual differences in multiple-task performance. Unlike previous experiments, which have been concerned primarily with isolating a general timesharing ability, this study relies on an experimental rather than a correlational approach and uses the concept of differential stability to examine individual differences. Specifically, it attempts to demonstrate that there are consistent between-subject differences on very different types of task combinations when subjects are grouped on the basis of the response strategy used to perform two discrete tasks concurrently.

LITERATURE REVIEW

Background

Historically, psychologists have examined individual differences in multiple-task performance only through the concept of a general timesharing ability. Although there is no widely accepted definition of a timesharing ability, for the purposes of this paper it is an ability which affects only multiple-task performance and is independent of the performance level of any of the component tasks. Thus, traditionally psychologists have sought to demonstrate that some individuals perform better on all task combinations than others irrespective of their single-task performance. Because individual differences in multiple-task performance have not been examined as a function of either subject or task variables, only literature addressing the related question of a general timesharing ability will be reviewed.

Although some timesharing experiments were conducted before the turn of the century (Binet, 1890; Sharp, 1899), the first systematic attempt to isolate a general timesharing ability was conducted by McQueen (1917). He reasoned that if a general timesharing ability exists, performance on a given dual-task combination should correlate fairly highly with performance on other dual-task combinations. To test this hypothesis, McQueen required his subjects to perform five different dual-task combinations. The first required the subject to tap and add printed numbers simultaneously. In the second the subject sorted cards and counted out loud by threes. The third combination required the subject to cross out "o"s on a printed page while putting discs on a needle that was hidden from view. The fourth required the subject to make size discriminations of circles tachistoscopically presented. The fifth task was a dotting task that could be performed with either hand alone or both hands simultaneously. Stimuli for the two-hand condition were independent of each other.

The five dual-task tests were administered to 35 school children between the ages of 11 and 13. The first three combinations were administered twice, once on each of 2 successive days. For each combination the subject received one trial on each component task alone before and after two dual-task trials. For the fifth combination the subject received one trial on each hand alone and one trial using both hands simultaneously at each of three different rotation speeds. Scores on all tasks were normalized; dual-task scores were the composite of the normalized scores on the component tasks.

The fourth task combination currently would not be considered a timesharing task and will not be considered further. McQueen found that the rank order of subjects on dual-task performance often was considerably different from that of single-task performance. However, there was no correlation between a subject's change in rank between single- and dual-task conditions across dual-task combinations. Additionally, all partial correlations between dual-task combinations with performance on the component tasks held constant were unreliable. These last two findings together provide no evidence for a general timesharing ability.

More recently, Sverko (1977) attempted to isolate a general timesharing ability using four different experimental tasks: rotary pursuit, choice reaction time to visually presented digits, mental arithmetic, and two-choice auditory discrimination. Sixty female subjects first were given 3 min of practice on each task alone to allow single-task performance to reach a stable level. Next, the subjects performed a fixed sequence of one 1-min single-task trial on each experimental task followed by one 1-min trial on each of the six dual-task combinations. This sequence was repeated twice with 1-min rests between trials.

Two analyses were conducted to isolate a general timesharing factor. One analysis was a principal component analysis of the product moment correlations. The four factors extracted from the analysis were clearly specific to each of the experimental tasks; no evidence of a timesharing factor was found. Sverko also calculated a timesharing decrement score, the percent of single-task performance lost under dual-task conditions for each task in a given combination. The decrement scores for each component task then were summed to obtain a total decrement score. Correlations between combinations having no tasks in common revealed no consistent individual differences in dual-task decrements across task combinations. Thus, this analysis also provides no evidence for a general timesharing ability.

Jennings and Chiles (1977) attempted to isolate a general timesharing ability by examining performance on each of six tasks when performed alone and in two groups of three. One task, a warning lights task, required the subject to push a button whenever one of ten lights changed state. For the meter monitoring task the subject monitored four meters. Each meter had a pointer moving at random around a mean vertical position. The subject pressed the corresponding switch whenever he detected a shift in the mean position of a given pointer. The third task was a two-digit mental arithmetic task. In the pattern identification task the subject determined if one, both, or neither of two comparison patterns matched a previously displayed standard pattern. For the group problem solving task each subject had one pushbutton. The subjects determined the order in which the buttons were to be pushed by using a trial-and-error search sequence. The final task was two-dimensional compensatory tracking.

A total of 39 subjects were tested in groups of five (the experimenter acted as the missing subject on occasion). Testing was conducted on each of 3 successive days. On the first day the subjects performed each of the six tasks alone. On the second day the subjects performed each of the three tasks comprising one of the complex tasks alone and then performed the complex task. On the third day the subjects performed both complex task combinations.

The data then were factor analyzed. One factor emerged which appeared to be a timesharing factor; the meter monitoring task and the warning lights task loaded on this factor when they were performed as part of the complex task but not when they were performed alone.

Wickens, Mounteford, and Schreiner (1979) used an approach similar to that of Sverko's except that task selection was based on a structure-specific reservoir model of attention. Accordingly, four specific dimensions of processing requirements were considered in task selection: input modality, cerebral hemisphere of processing, pacing, and response continuity.

Four tasks were selected. The first was a standard sub-critical tracking task. In this task the subjects were required to keep an error cursor in the middle of a display screen. The control dynamics provided an unstable positive feedback loop that drove the error cursor to the edge of the display at a velocity proportional to the error.

The second task was a number classification task. Two numbers appeared on the display screen that could vary in two dimensions: size and name. If the pair were different numbers but the same size, the subject pushed one key. If the pair did not meet these two criteria, the subject pushed a second key.

For the third task, a spatial line judgement task, the subject was shown two obliquely oriented straight lines which varied both in length and angle of projection. The two lines were nonoverlapping and both were either above or below a horizontal reference line. The subjects visually projected the two innermost lines to their imaginary point of intersection and decided if the intersection point was above or below the reference line. The subjects then pressed one of two response keys.

In an auditory running memory task subjects heard a series of 38 letters in either the left or right ear. One letter was presented every 3 sec. The subject pressed one of two keys according to whether each letter was in alphabetical order relative to the preceding one.

Each task was paired with every other task and, except for the auditory memory task, each task also was paired with itself. Forty right-handed males performed each task pairing on each of 3 days.

Two different factor analyses were performed on the data from Days 2 and 3. The first was performed on the single-task measures and the average (across task pairs) dual-task measures for each task. The second was performed only on the decrement scores. For both analyses a two-factor solution was specified first followed by three-factor solution. The analyses showed little evidence for a general timesharing factor.

Keele, Neill, and deLemos (1978) attempted to isolate a general trait of attention flexibility. This trait, which was defined as the ease with which a person can switch set from one expectation to another, is not identical to the general timesharing ability which has been discussed thus far. However, because operators of complex systems must occasionally perform low probability tasks, attention flexibility may have an effect on multiple-task performance and will be reviewed for that reason.

Fifteen subjects performed each of four tasks during several sessions. In the first task, the priming task, a warning signal preceded one of four possible stimuli. On one-half of the trials the warning light consisted of a neutral-colored plus sign. This warning light indicated that all of the four stimuli were equally likely to follow. On the other half of the trials the warning signal was a red light indicating that one of the following stimuli would occur with a probability of 0.7. A measure of attentional flexibility was obtained by subtracting the reaction time to stimuli after the neutral plus sign from the reaction time to unlikely events following the red warning light.

The second task, the rare event task, used the same stimuli and warning lights as the preceding task. However, one of the stimuli occurred on only 1% of the trials. A measure of attentional flexibility to this stimulus was obtained in the manner described above.

The third task, the alternation task, required the subjects to switch set in a predictable manner. The subject saw six stimuli: three colors which the subject responded to with his left hand and three forms which the subject responded to with his right hand. There were two types of trial blocks. In one the subject expected and responded only to one of the two types of stimuli. In the second the subject responded to both types but the signal types were strictly alternated. Two different response-stimulus intervals (RSI's) were used -- 50 and 750 msec. Two measures of attentional flexibility were calculated from this task. For the first the pure block reaction times at the fast rate were subtracted from the alternation reaction times at the fast rate. For the second measure a similar score was calculated for the slow RSI. This difference score then was subtracted from the preceding difference score.

The fourth task was a dichotic listening task. The subject heard word pairs at a rate of 2/sec consisting of either color names or a color and a digit. Subjects were to report any digits they heard in a predesignated ear. After three to six pairs another message indicating which ear to focus on was given. Four strings of stimulus pairs were presented before the subject was permitted to rest. The measure of flexibility was the number of errors in reporting the correct digits.

Keele et al. reasoned that if there is a general trait of attention flexibility, then the different measures should correlate positively. Although some of the correlations were small, the measures of flexibility obtained from the alternating task correlated significantly with measures from the other three tasks. However, few of the other intercorrelations were significant.

Summary

Only one of the preceding experiments (Jennings and Chiles, 1977) showed any evidence of a general timesharing ability. However, the factor located in this experiment may be a scanning factor. Although scanning is a valid form of timesharing behavior, it is not directly concerned with central processing and will not be considered further.

Also, any conclusions about the existence of a general timesharing ability based on the preceding experiments should be made only with extreme caution for two reasons. First, apparently none of the task combinations were examined to determine if they required central timesharing for adequate performance. Although all of the preceding combinations did show a dual-task decrement, such a decrement may be induced by physical factors--such as the inability to see the stimuli for both tasks concurrently--and is not indicative per se that the tasks must be centrally timeshared.

Second, all the experiments interpreted patterns of correlations to determine if a general timesharing ability was present. Although this approach is valid, a more experimental approach might give different results. Finally, as noted in the Introduction, lack of evidence for a general timesharing ability does not imply that individuals do not differ consistently on various task combinations.

EXPERIMENTAL RATIONALE

Approach

One of the major problems in demonstrating consistent individual differences in multiple-task performance is selecting task combinations where specific timesharing abilities, if they exist, will affect performance in measurable amounts. Although there is no accepted technique for selecting such combinations, one method relies on an analogy between multiple- and single-task performance. At any point in time single-task performance is generally thought to be determined by some combination of the subject's ability and his skill. By analogy multiple-task performance at any point in time may be thought to be determined by the subject's performance on each component task, his timesharing skills, and his timesharing abilities (if they exist). Therefore, combinations which demonstrably involve timesharing skills are the ones which should be examined for evidence of consistent individual performance differences after adjustments for individual differences in performance on the component tasks have been made. Timesharing skills, such as parallel processing and rapid intertask switching, will be assumed to be skills which contribute only to multiple-task performance and which cannot be learned under single-task conditions.

One technique for demonstrating that timesharing skills are involved in a given task combination partitions any improvement found with practice under multiple-task conditions into components due to improved single-task skills and a component due to improved timesharing skills. This technique, which achieves this separation during two stages of training, is illustrated in Figure 1. During Stage 1, which involves single-task training, each component task is practiced until performance has stabilized. Then during Stage 2, which is predominantly dual-task training, single-task performance is reassessed

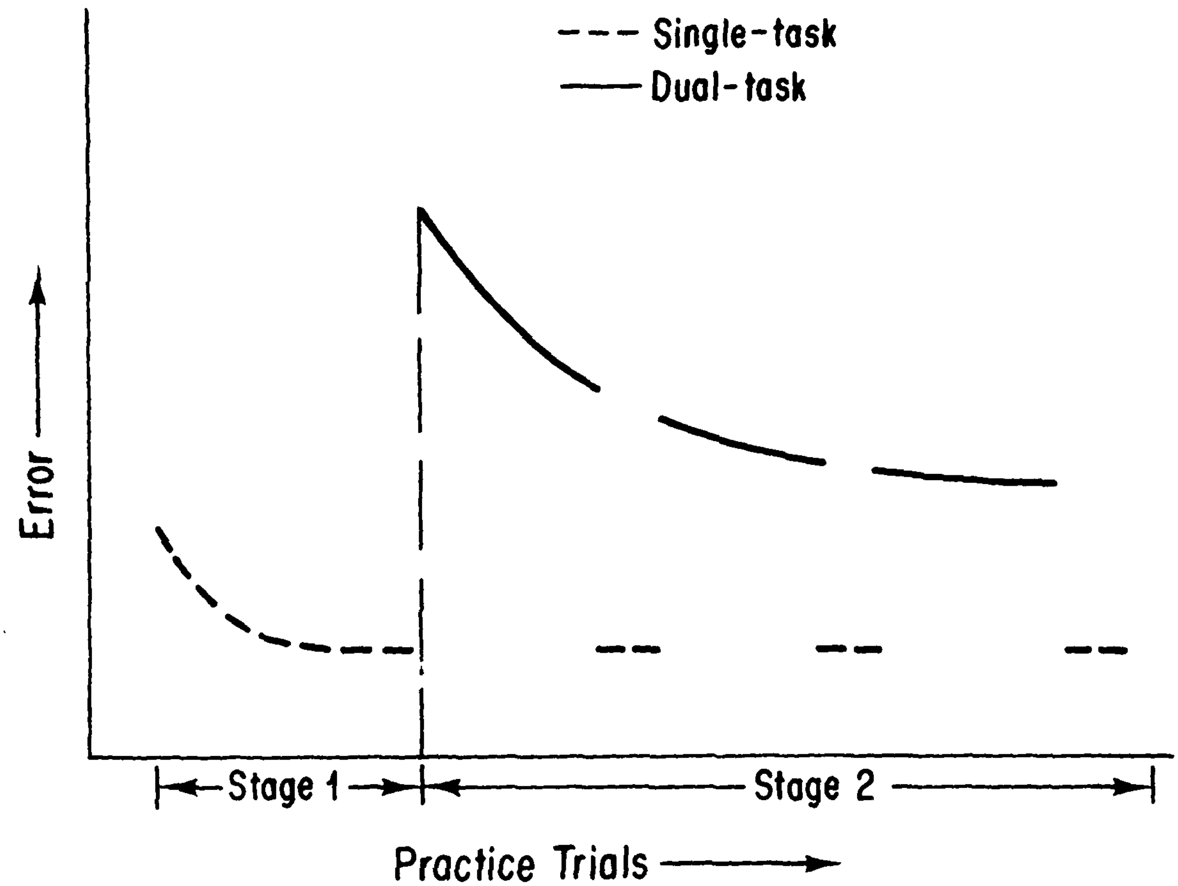

Figure 1. An example of the measurement technique used to identify timesharing skills. During Stage 1 practice on each component task is continued until performance begins to stabilize. During Stage 2 practice is primarily on the dual-task combination. However, single-task performance periodically is reassessed to determine its stability.

periodically to determine its stability. If multiple-task performance improves during Stage 2 while single-task performance remains stable, the improvement may be attributed to the development of timesharing skills.

To demonstrate statistically the development of timesharing skills using this technique, a two-factor (secondary-task load by trials) analysis of variance may be applied to the Stage 2 data. Two effects must be statistically reliable to demonstrate the development of timesharing skills: the effect of secondary-task load indicating a dual-task decrement and the secondary-task load by practice interaction. This interaction in conjunction with stable single-task performance implies that the improvement in dual-task performance is the result of improved timesharing skills, not improved single-task skills.

Dual-task Performance Measurement

As mentioned above, individual differences in single-task performance must be taken into account before inferences about individual differences in timesharing ability can be made. Although there are several ways in which this can be done, the technique which will be used in this study relies on difference scores. As shown in Figure 1, each block of Stage 2 dual-task trials is preceded and followed by single-task trials on each component task. These single-task trials can be used as a baseline for both the dual-task decrement and any subsequent improvements in dual-task performance. For example, assume Task X and Task Y are being studied. To correct dual-task performance on Task X for the baseline, performance on the single-task Task X trials preceding and following a given dual-task block would be averaged. This value would be subtracted from the dual-task performance of Task X on each of the intervening dual-task trials. The same procedure would be used to correct Task Y for its single-task baseline. Thus, an individual's performance measure on a given dual-task trial would be a difference score between the real dual-task performance score and the estimated single-task baseline. Each dual-task performance measure, therefore, is corrected for the individual's single-task baseline.

Task Selection

Using the guidelines specified above, three task combinations were selected for inclusion in the experiment (detailed descriptions of each task are given in the Methods Section). Two of these combinations, tracking and tracking (TR-TR) and memory and classification (ME-CL), were used in previous experiments and were demonstrated to require timesharing skills using the preceding technique. Table 1 describes each combination in terms of four major task characteristics known to affect dual-task performance.

The third task combination, dichotic listening, had not been used previously by the first author. However, it was selected for use in this experiment for three reasons. First, it has all of the characteristics of a true dual-task combination as discussed in an earlier publication (Damos, 1977). Second, there is a large body of data available on this task combination. Third, it uses the auditory modality as the input channel. Because the other two combinations use the visual modality, input channel could be examined as a possible source of individual differences.

There were, however, several problems associated with this combination. The most difficult problem was determining the single-task counterpart of dichotic listening. Logically, this appeared to be monaural listening (stimuli presented to one ear only). Extensive pretesting indicated, however, that the subjects frequently detected 100% of the targets under monaural conditions but only 20 to 30% of all of the targets presented under dichotic conditions. The existence of a monaural ceiling prohibited the use of the technique described earlier for identifying the development of timesharing skills because single-task performance would be artificially stable. Subsequently, selective listening was examined and found to give a lower probability of detection than monaural listening. It was recognized that selective listening may not be the single-task

TABLE 1

Description of Each Task Combination in Terms of Four Major Characteristics

Characteristic	Task Combination: Tracking	Memory - Classification	Dichotic Listening
Input Modality	Visual	Visual	Auditory
Central Processing	Spatial	Verbal	Verbal
Response	Continuous	Discrete	Discrete
Pacing	Paced	Unpaced	Paced

counterpart of dichotic listening. However, it seemed preferable to treat it as such and administer the listening tasks in the same fashion as the other two combinations rather than use a completely different procedure for dichotic listening.

Individual Differences as Reflected in Strategy

As indicated in the Literature Review, there is little evidence for a general timesharing ability. However, it may be that a fine-grained approach to multiple-task performance would be more fruitful than the global approach that has been used in the past. That is, individuals may differ on subtle aspects of multiple-task performance that are not reflected in gross performance measures. It also is possible that individuals do differ consistently on multiple-task performance but these differences are masked by other task variables. For example, if some individuals can process several sources of information well when all inputs are in the visual modality but process several sources poorly when all inputs are in the auditory modality while others are the exact opposite, then a very consistent pattern of performance could be found; but there would be no evidence for a general timesharing ability as it has been construed previously.

The experiment reported in this paper uses a fine-grained approach in examining individual differences in multiple-task performance. Although an individual might be classified along numerous dimensions of multiple-task behavior, subjects in this study will be classified according to which of three identifiable response strategies they uses to perform the ME-CL combination. These three strategies are a simultaneous response strategy, an alternating strategy, and a massed strategy. A simultaneous response strategy is one in which the subject responds to both stimuli within some arbitrarily small interval (less than 100 msec). An alternating strategy is one in which the subject alternately makes one response to each task. If more than two responses are made consistently to one task before switching to the other, the strategy is classified as massed.

Previous research (Damos, 1977) indicated that a subject's response strategy was easily identified as one of the three described above. Additionally, the subjects were found to adopt one of the three strategies within the first 3 min of performance and to use that strategy throughout the rest of the experimental session. The strategy employed was the major determinant of dual-task performance; the simultaneous response subjects performed the best on all dual-task measures examined, the alternators had the next best performance, and the massed subjects had the poorest. Examination of single-task performance indicated that these dual-task differences could not be attributed to differences in single-task performance. Additionally, other unpublished research by the first author demonstrates that subjects who are asked to change strategies never perform as well as subjects who use their natural strategy.

These findings imply that the strategy the subjects use to perform the ME-CL task combination may reflect some individual differences in multiple-task performance. Therefore, subjects were divided into groups on the basis of the response strategy used to perform the ME-CL combination and between-group differences in performance were examined across task combinations.

Task Stabilization

Recent work by Jones (1972) and Jones, Kennedy, and Bittner (1979) demonstrates that consistent individual differences in performance can be found only when performance on a given task has stabilized. That is, with more practice on the task the mean either does not change or changes slowly, the variance no longer changes, and the intercorrelation between post-stabilized trials remains constant.

If a task has not achieved stability, then most probably the intertrial correlation matrix will have the superdiagonal form. This form is characterized by a decrease in the intertrial correlations as a function of interpolated practice. Thus, if an intertrial matrix has simplex structure, the correlations will decrease from left to right across a given row and will increase from top to bottom in each column. Alvares and Hulin (1972, 1973) and Dunham (1974) have interpreted the superdiagonal form as evidence that the subject's abilities are changing with practice. If this is the case, then it is useless to examine prestabilized data for individual differences. Because none of the preceding experiments examined their data for stability, unstable and stable data may have been analyzed, which may explain why no consistent individual differences were found.

In this experiment the point at which performance becomes stable on each task combination will be determined and only stabilized data will be analyzed.

METHOD

Tasks

Classification (CL). For this task two randomly selected digits between five and eight were presented simultaneously to the subject. The digits varied on two dimensions: size and name. The subject determined the number of dimensions on which the stimuli were alike and then pressed one of three keys on his left-hand keyboard. As soon as the subject pressed a key, the pair was erased and a new pair presented 2 msec later.

Two dependent variables were calculated for each trial: the average interval between correct responses (CRI) and the percentage of correct responses to the total number of responses emitted. The average CRI differs from the more common average reaction time in that incorrect responses are not counted in its calculation. That is, when an incorrect response occurs, the CRI is the time between the preceding correct response and the next correct response including the time during which the incorrect response was made. Both the percentage of correct responses and the CRI were displayed to the subject at the end of each single- and dual-task trial. Under single-task conditions the display subtended a visual angle of 0.22° by 0.36°.

Memory (ME). In this task randomly selected digits between one and four were presented sequentially to the subject. The subject retained the most recently displayed digit in memory while responding to the preceding digit. For example, if the first stimulus were "1" and the second "3", the correct response to the "3" would be "1". Responses were made by pressing one of four keys on the right-hand keyboard. The keys were numbered from left to right beginning with "1". The response to the first stimulus of any trial was always "1". As soon as a response was made, the stimulus was erased and the next one was presented.

Two dependent variables were recorded: CRI and the percentage of correct responses. At the end of each single- and dual-task trial the CRI and the percentage of correct responses were displayed to the subject. Under single-task conditions the stimulus subtended a visual angle of 0.22° by 0.14°. Under dual-task conditions the digits for the CL task were presented on the left side of the display screen (see Figure 2); the digit for the ME task was presented on the right side. The visual angle subtended by the display was 0.72° by 0.22°.

Tracking (TR). Two identical one-dimensional compensatory tracking tasks each required the subject to keep a moving circle centered in a horizontal track by making appropriate left-right manipulations of a control stick. One task was controlled by each hand. The inputs to the two displays consisted of the sum of sine waves of .02, .03, .07, .13, .23, .41, .83, 1.51, and 3.07 Hz. The inputs to the two displays were independent. The control systems had mixed first- and second-order dynamics with weightings of 0.10 and 0.90 respectively.

Average absolute errors were calculated for each task and presented to the subject at the end of each trial, one indication for single-task trials and two for dual-task trials. Additionally, the positions of the control stick and the error cursor were recorded every 100 msec for later offline analysis. Figure 3 shows the display of the TR-TR combination. The tracking tasks that were controlled by the left and right hands were appropriately offset to the left and right of the display center. The visual angles subtended by the display were 3.41° by 0.29°.

Listening. Each trial in this task consisted of a series of 100 stimulus pairs presented dichotically to the subject. The stimuli consisted of the digits zero through nine and all letters of the alphabet except W, J, H, I, and T. These letters were not used because pretest data indicated that their probability of detection was either very high or very low. The letters were

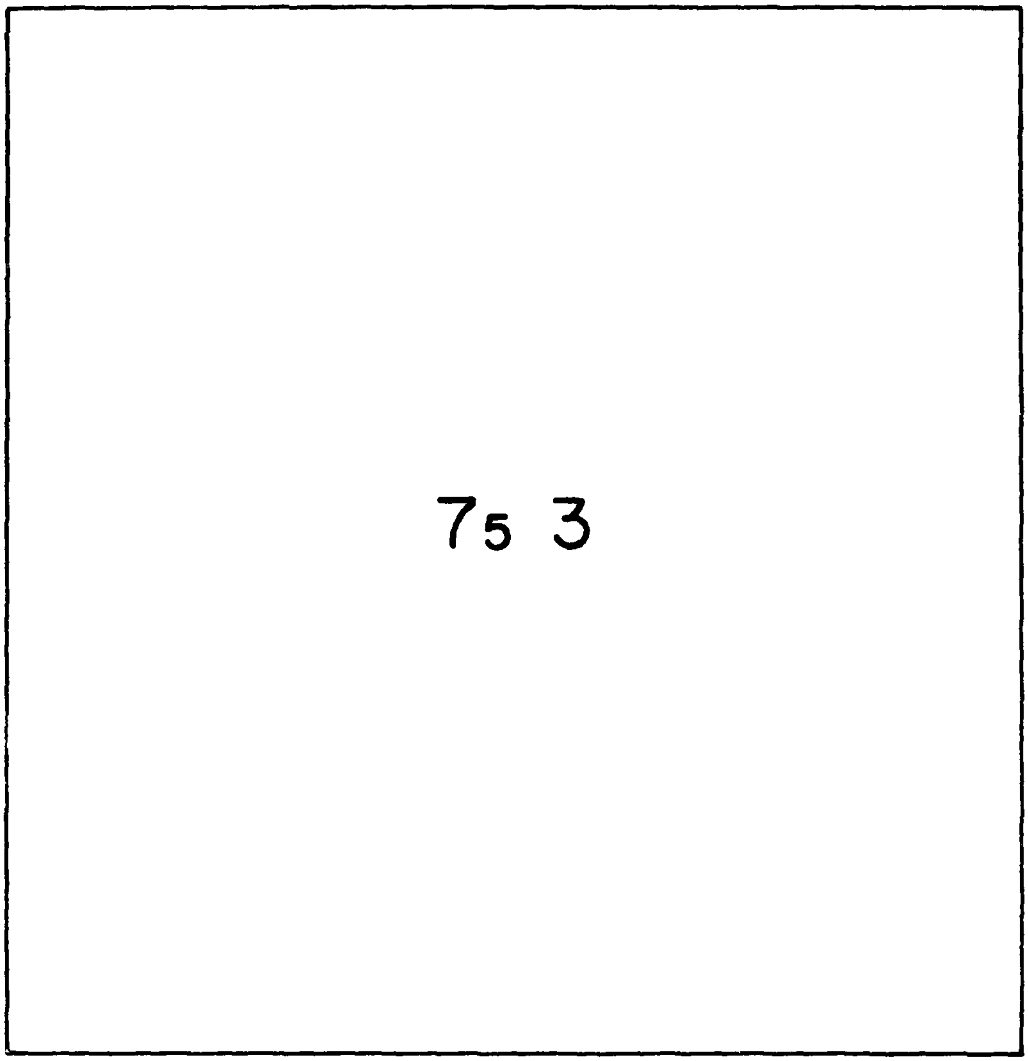

Figure 2. The dual-task memory-classification display.

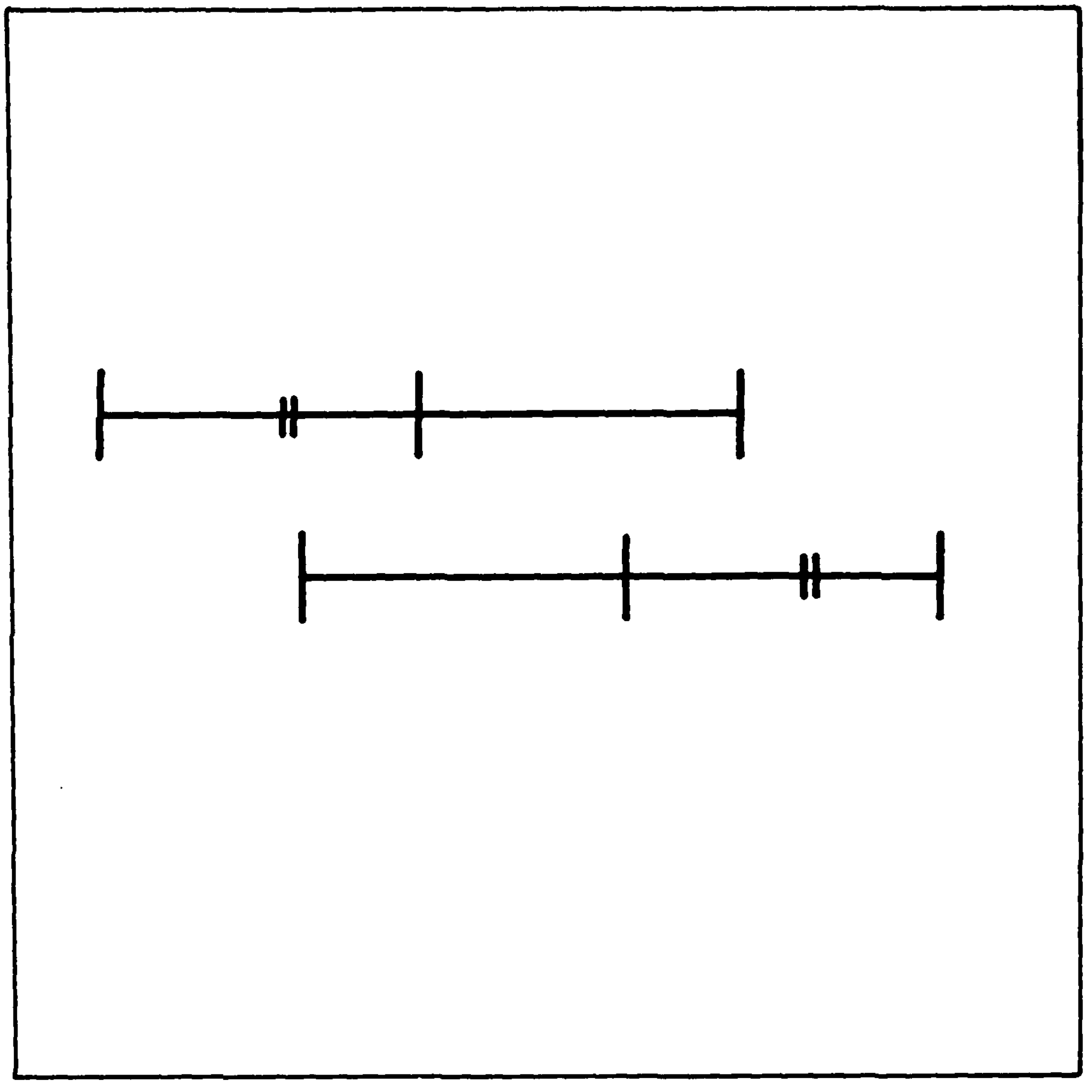

Figure 3. The dual-task tracking-tracking display.

targets and could appear in either ear alone or both ears simultaneously. An equal number of targets was presented to both ears during a trial and could vary from 8 to 12 per ear. Half of the targets during a given trial were paired with targets in the opposite ear, the other half were paired with numbers. The average probability of a target was $<$ 0.1 for each ear. If a target appeared in the left ear, the subject pushed his left-hand response key; if it appeared in the right, he pushed his right-hand response key. Stimuli were presented at 56 dB(A) against a background of white noise which raised the overall sound level to 71 dB(A) with a -14 dB signal to noise ratio. The interstimulus inverval was 750 msec and the average duration of the stimuli was 325 msec.

Under selective listening conditions subjects concentrated only on one ear, ignoring information presented in the opposite ear. Under dichotic conditions subjects attended to both ears equally. Each pair of stimuli were aligned to give simultaneous onset. Reaction times were recorded for each response.

Apparatus

A Processor Technology Microcomputer with a Helios II disc system recorded all responses and performed all timing. This system also displayed all inputs for the TR, CL, and ME tasks on a KOYO Model TMC-9M CRT.

TR. The forcing function was recorded on a cassette tape and was played on a Phillips Minilog 4 Data Recorder. The output of the recorder was fed through filters that were implemented on two EAI TR-20 analog computers to provide the desired power spectrum of the forcing function. The control system dynamics also were programmed on one of the EAI TR-20 computers. Subjects tracked the function using a pair of Measurement Systems Incorporated Model 541 Two-Axis Gimbal Joysticks. Both sticks were modified to permit movement in the left-right dimension only.

ME, CL. Subjects made their responses for these tasks by depressing a key on each of two 4 by 4 matrix-type Micro-Switch Model SW-10196 keyboards mounted in the table in front of them. The keys which were employed had no identifying marks which would connect them to the stimuli.

Listening. The stimuli for this task were created using a VOTRAX Voice Synthesizer at the Naval Aerospace Medical Research Laboratory at Pensacola, Florida. The tape was played on a TEAC A-2340 reel-to-reel tape deck and presented through Koss/E.9 headphones to the subject. White noise was produced using a Grason-Stadler 1724 noise generator and superimposed on the stimuli through a SONY MX-20 sound mixer. Subjects responded to the stimuli by pressing one key on each of the two keyboards described above.

Design

A within-subject repeated measures design with one independent variable, practice, was used. The experiment was conducted on 4 consecutive days. The task presentation order was the same for all subjects.

Subjects

Subjects were right-handed native English speaking males between the ages of 18 and 35 who responded to advertisements placed in the campus newspaper and in campus buildings. They were required to be flight naive with no significant physical handicaps and have good hearing and vision. One subject failed to meet the hearing standards and was excused from the experiment. Thirteen subjects began the experiment, but following a change in procedure, data from the first two subjects were discarded. Subjects were paid $2.50 per hour.

Procedure

Day 1. Before taking part in the experiment, all subjects were given vision and hearing tests. The vision examination consisted of a near acuity test involving both eyes simultaneously. The test was terminated when a subject incorrectly identified two consecutive stimuli or correctly identified all stimuli up to and including the 20/20 cutoff point. Hearing was tested at each of six different frequencies using an intermittent pure tone played through headphones. Right and left ears were tested separately with the dominant or preferred ear being tested first. Subjects whose hearing was greater than +15dB from the 0dB standard for any of the test frequencies were not allowed to participate.

The Purdue Pegboard Test was used to obtain a basic measure of dexterity and coordination for each subject. Subjects received a right- and then a left-hand trial, followed by a trial in which both hands were used simultaneously. Each trial lasted 30 sec.

On Day 1 subjects performed under single-task conditions only. For the tracking task subjects received taped instructions (see Appendix A) on the use of the control sticks and the relation of stick movement to the tracking display. They performed ten trials, beginning with the right hand and alternating between hands on each successive trial. The trials were each 1 min long followed by a 1 min rest pause. During the rest pause feedback was provided on the subject's performance.

Following the tracking task, subjects heard taped instructions for the selective listening task (see Appendix B). Before performing the first trial, subjects heard a tape of the letters and numbers which would be used as stimuli. Subjects performed six trials per ear, starting with the right ear and alternating between ears. The experimenter reminded them which ear to concentrate on before each trial. Each trial lasted 75 sec with a 40 sec rest pause between trials. No feedback was provided to the subjects concerning their performance on the listening task.

After the selective listening task subjects were given taped instructions for the ME task (see Appendix [illegible]). After performing one ME trial, subjects then were presented with taped instructions for the CL task (see Appendix D). They then performed 11 trials, beginning with the CL task and alternating with the ME task. All trials were 1 min long with a 1 min pause between trials. During the rest pauses subjects were given feedback on their performance on the preceding trial.

The entire first session lasted approximately 1.5 hours.

Days 2, 3, and 4. On the second day of the experiment subjects performed under dual-task conditions. Subjects first performed two single-task tracking trials, one on each hand. Next, subjects were given dual-task tracking instructions verbally. Subjects were told to give equal attention to both hands and to make the absolute error as small as possible for both hands. Subjects then performed two blocks of five dual-task trials. Each dual block was followed by both a right-hand and a left-hand single-task trial. All trials were 1 min long followed by a 1-min rest pause. Each pair of single-task trials began with the right hand. Feedback was provided after each trial. A 2-min pause was given after the second pair of single-task trials. A 5-min pause followed the last pair of single-task trials.

Immediately following the 5-min pause, the subjects performed a pair of selective listening trials, one on each ear. Next, subjects received taped instructions for dichotic listening (see Appendix E). They were instructed to give equal attention to both ears. Subjects then performed two blocks of seven dichotic trials. Following each dichotic block, subjects performed a pair of selective trials. All trials were 75 sec long, followed by a 40-sec rest pause. A 2-min pause was given following the second pair of selective trials with a 5-min pause after the final pair. At no time during the listening task did subjects receive any feedback.

In the final portion of the session subjects performed the discrete tasks ME and CL. First they were given two trials each on ME and CL, beginning with the ME task and then alternating between tasks. Subjects then were given taped instructions for performing under dual-task conditions (see Appendix F). Subjects performed two five-trial blocks under dual-task conditions, each block being followed by a single-task ME and a single-task CL trial. All trials were 1 min long followed by a 1-min pause, during which feedback was given. A 2-min pause was given after the second pair of single-task trials.

Days 3 and 4 followed the same pattern as Day 2 except that the subjects simply were reminded of the instructions for each task. Each session on Days 2, 3, and 4 required approximately 2.3 hours.

RESULTS

Development of Timesharing Skills

ME-CL combination. Performance on the ME-CL combination on Days 2, 3, and 4 may be seen in Figure 4. To determine if timesharing skills were developed, the technique discussed earlier was used. The second, fifth, and tenth dual-task trials on each day and the single-task trials preceding and following each dual-task block were selected for examination. Both the ME and the CL data were examined for violations of the homogeneity assumption of the analysis of variance (ANOVA). Only the CL data were found to violate this assumption ($F_{max_{18,10}} = 233.2659$, $p < .01$). Subsequently, a reciprocal transformation was used to meet the homogeneity assumption ($F_{max_{18,10}} = 5.8087$, $p > .05$).

A repeated measures three-way ANOVA conducted on the transformed data revealed significant main effects of both load ($F_{1,10} = 1053.3741$, $p < .001$) and trials ($F_{8,80} = 20.1137$, $p < .001$). The load by trials interaction also was significant ($F_{8,80} = 3.6686$, $p < .001$). Single-task CL performance was essentially stable, improving less than 130 msec over the 3 days of Stage 2 practice.

An identical repeated measures ANOVA was conducted on the ME data. Both the main effects of load and trials were significant ($F_{1,10} = 93.0074$, $p < .001$ and $F_{8,80} = 9.0637$, $p < .001$). Additionally, the load by trials interaction was significant ($F_{8,80} = 6.7673$, $p < .001$). During Stage 2, performance on the ME task improved only 270 msec under single-task conditions.

TR-TR combination. Performance on the TR-TR combination on Days 2, 3 and 4 may be seen in Figure 5. To determine if timesharing skills were

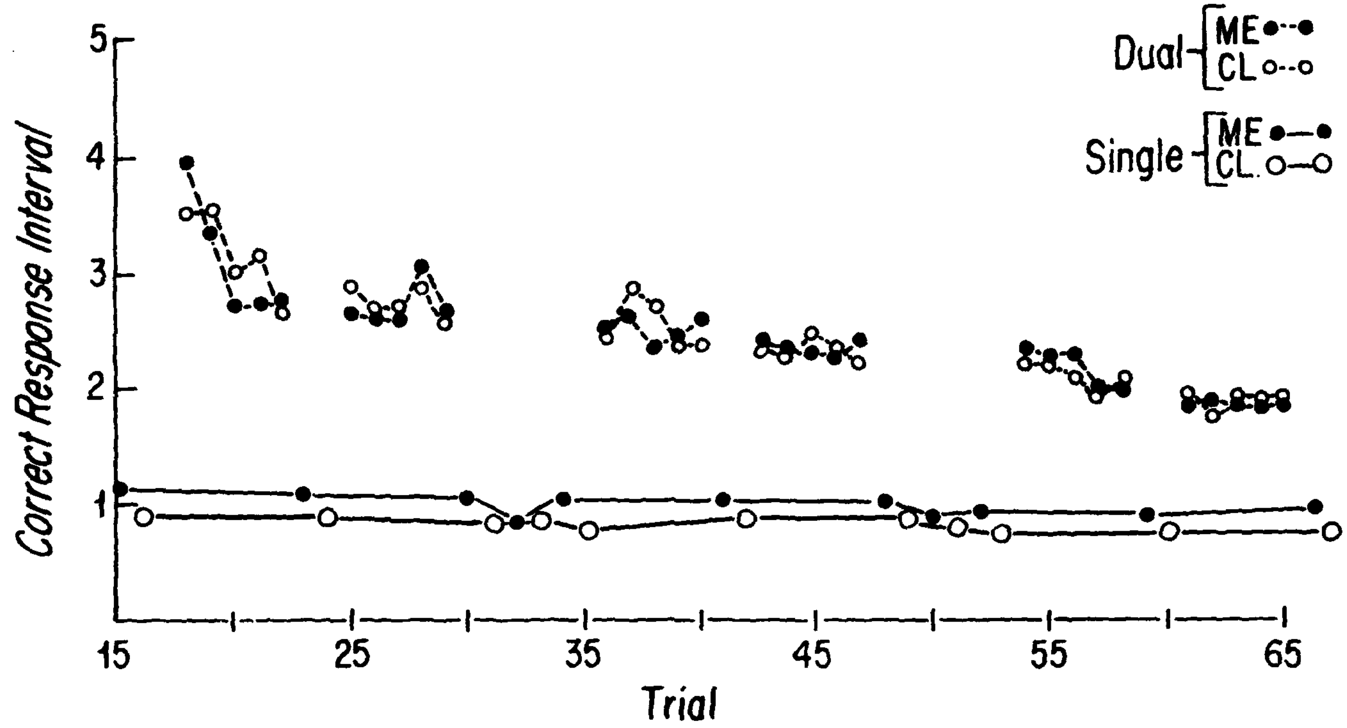

Figure 4. The correct response interval (CRI) on Days 2, 3, and 4 for the memory and classification tasks under single- and dual-task conditions.

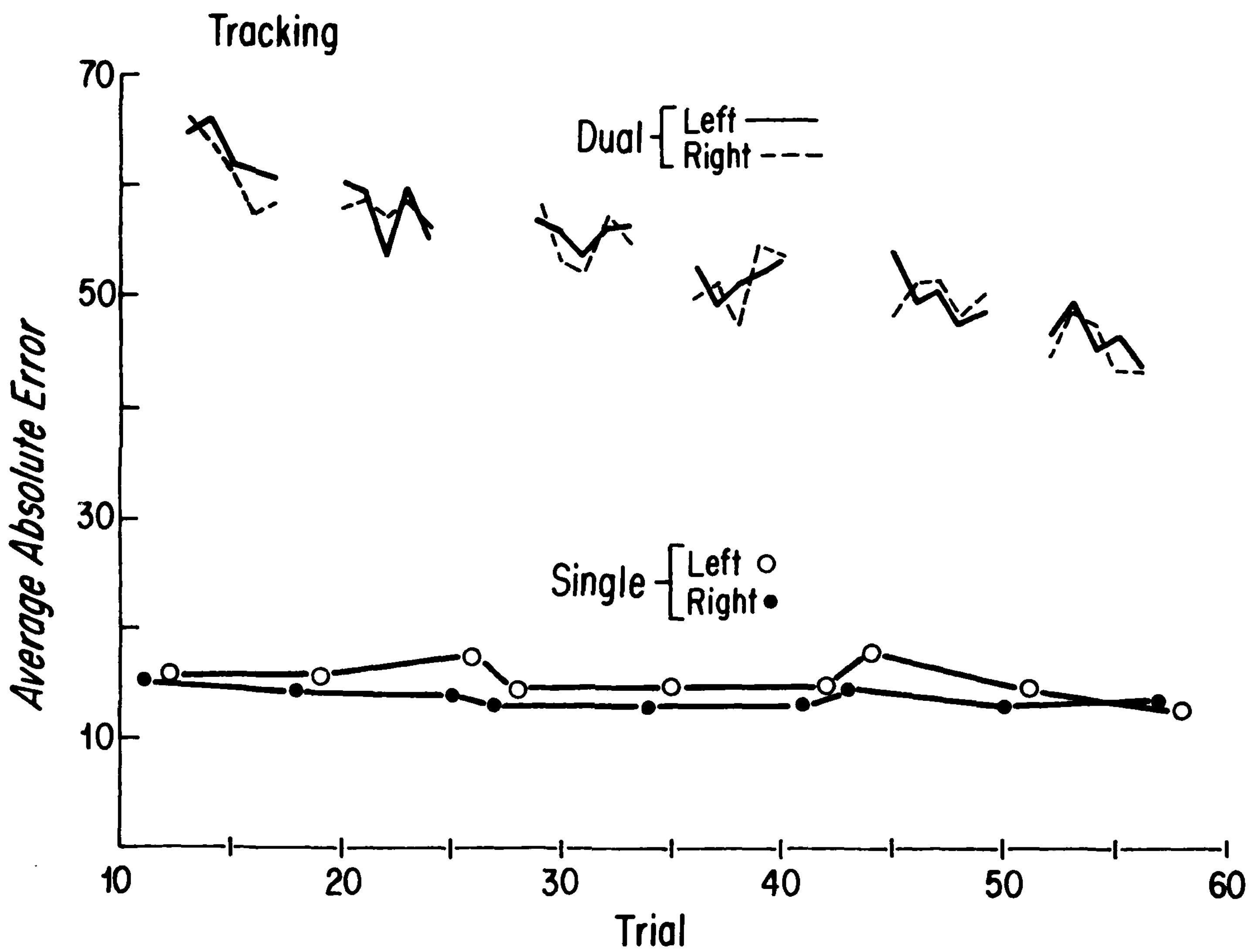

Figure 5. The average absolute error on the tracking tasks on Days 2, 3, and 4 under single- and dual-task conditions.

learned in the TR-TR combination, a three-way repeated measures ANOVA was conducted on the data. Preliminary analyses indicated that there was no significant difference between hands on either single- or dual-task performance ($p > .05$). Therefore, performance was averaged over hands on all dual-task trials and successive left- and right-hand single-task trials also were averaged to obtain one single-task score.

Again, the second, fifth, and tenth dual-task trials of each day were analyzed. All single-task data on each day were used in the analysis. Because the homogeneity of variance assumption was not violated ($F_{max_{18,10}} = 6.9757$, $p > .05$), the analysis was conducted on the raw data. Again both the main effects of load ($F_{1,10} = 282.2161$, $p < .001$) and trials ($F_{8,80} = 14.6178$, $p < .001$) were significant. The load by trials interaction also was significant ($F_{8,80} = 8.6171$, $p < .001$). Again, single-task performance was quite stable during Stage 2; it improved only 2.8%.

Dichotic listening. Performance on the dichotic listening task cannot be examined for evidence of the development of timesharing skills in the manner used above for two reasons. First, some argument can be made that selective listening is not the appropriate single-task baseline. Second, even if selective listening is accepted on the appropriate baseline, performance improved significantly over Days 2 through 4 ($F_{2,20} = 3.4950$, $p < .05$). Because the technique used to demonstrate development of timesharing skills requires a stable single-task baseline, this technique can not be used to analyze the listening data. Thus, any development of timesharing skills must be inferred by examining changes in dichotic listening performance alone. Two variables that may be examined for timesharing skills are the probability of detecting simultaneous targets ($P(Hit|Hit)$) and the difference in reaction time between the first and second responses when both targets have been detected.

If the subject develops skills in parallel processing or rapid intertask switching, then with practice he should detect more simultaneous targets. Additionally, his probability of making a false alarm on one channel when a target appears on the other channel ($P(FA|Hit)$) should remain constant or decrease. However, if the subject learns only the statistical properties of the task, then he will know that if he detects a target on one ear, there is a 50-50 chance that a target has occurred on the other channel. Thus, if the subject only learns the properties of the task, any increase in $P(Hit|Hit)$ should be accompanied by a comparable increase in $P(FA|Hit)$.

$P(Hit|Hit)$ and $P(FA|Hit)$ were calculated for each subject for each block of dichotic trials on Days 2, 3, and 4. A linear regression was performed on $P(FA|Hit)$ as a function of practice. The best fitting linear equation, $P(FA|Hit) = .056 + .006B$ where B is the block number, was found to have a slope not significantly different from 0.0. In contrast the corresponding equation for $P(Hit|Hit)$, $P(Hit|Hit) = .158 + .020B$, did have a slope significantly different from $0.0 (p < .05)$. This implies that the improvement in $P(Hit|Hit)$ was due to improved timesharing skills, not to a change in strategy favoring guessing.

The reaction times for simultaneous hits were examined for further evidence of the development of timesharing skills. If the reaction time of the first response remains constant or decreases with practice while the reaction time of the second response decreases or decreases at a faster rate than that of the first response, the decrease in the reaction time of the second response could be attributed at least in part to the development of timesharing skills.

The average reaction time for the first and second responses to contralateral targets for each subject was computed for each of the two dichotic blocks on Days 2, 3, and 4. A linear regression performed on the data indicated that neither of the two slopes were reliably different from 0.0($p > .05$) . This analysis, therefore, provides no evidence for the development of timesharing skills.

Strategy Analysis

Generally, it is not possible to classify a response strategy definitively on fewer than five trials and, of course, the more trials available for examination, the more positive the classification. An examination of the first ten dual-task trials (Day 2 performance) indicated that many subjects experimented with different strategies throughout these trials. However, by the second day of dual-task practice, the experimentation generally had stopped and a strategy had been selected. As indicated below, it was very easy to classify the strategy used on Days 3 and 4 for 9 of the 11 subjects.

To determine which strategy a subject used, an offline program analyzed the data from each trial on a response-by-response basis. The program analyzed three major features that permitted the experimenter to identify the strategy: the largest number of sequential responses emitted to each task, the number of simultaneous responses, and the number of switches between tasks.

To determine if two responses were emitted "simultaneously", the times at which the responses were made were compared. If the difference was less than some constant selected by the experimenter, the two responses were classified as simultaneous. If the difference was greater than this constant, it was assumed that the subject switched attention from the first to the second task. The difference between the times at which the responses were made (the onset difference time) then was stored and after all the data for a given trial had been analyzed, the onset differences were summed and divided by the number of switches to obtain an average switching time (it should be noted that this value also contains the processing time for the task).

Previous research (Damos, 1977) indicated that there was very little difference in the number of response pairs classified as simultaneous in a given trial when the acceptable response difference time was varied between 33 and 100 msec. That is, generally, if two responses were emitted simultaneously, the onset difference was between 1 and 5 msec. If, on the other hand, the subject had switched between the two tasks, the onset difference was on the order of 400 msec or more. Thus, practically, it was easy to distinguish between a simultaneous response pair and two stimuli which the subject processed and responded to sequentially.

For this experiment two responses must have been emitted within 33 msec of each other to be counted as a simultaneous pair (this constant is approximately 1/10 the fastest average single-task response time recorded for either the ME or the CL task). Subsequently, five subjects were found to use the simultaneous response strategy. The average onset difference for these five subjects was 4, 2, 3, 2, and 2 msec. The average number of switches per trial was 2.3, 0, 1.9, 0.3, and 0.2 respectively and the average switching time was 358, 0, 865, 706, and 37 msec. There was very little indication of sequential responding to either task; one subject made a few sequential responses on two trials, two subjects on one trial, and two subjects never made any. Thus, the low number of switches per trial and the few instances of sequential responding indicate that these subjects used a simultaneous response strategy.

Three subjects used the alternating response strategy. None of these three subjects emitted any simultaneous responses on Days 3 and 4 and two of the three never emitted more than one response to a task before responding to the other. The third subject used a combination of alternating and sequential responding but this occurred on only 2 of the 20 trials analyzed. Additionally, during both these trials only a few sequential responses (two to five) were made before the subject responded to the other task. The average switching time for the subjects was 1206, 920, and 1438 msec respectively. Thus, the response strategy used by these three subjects could be easily identified as alternating.

Three subjects were classified as using either a massed or a mixed strategy. The first subject clearly used a massed strategy. Generally, this subject emitted three or more responses to one task before switching to the other; during one trial he made 22 responses to the ME task before responding once to the CL task. This subject showed some evidence of alternating between the two tasks during only one trial but even in this case he frequently made two sequential responses to a task before responding to the other. This subject made no simultaneous responses during Days 3 or 4.

The second subject also made no simultaneous responses during either Day 3 or Day 4. This subject used predominately an alternating strategy on 11 of the 20 trials analyzed with short blocks of sequential responses (two to four) embedded in the trial at various points. On the trials where the subject used a massed strategy, he favored short blocks of two or three sequential responses and never emitted more than six sequential responses at any time.

The third subject mixed all three strategies between and within trials. Initially, this subject used an obvious massed strategy. However, during the second part of Day 3 he used all three types of strategies within a given trial. By the end of Day 3 he was using a simultaneous response strategy. During Day 4 he used a simultaneous response strategy on some trials, a massed with a simultaneous strategy on others, and all three strategies on the remaining trials.

Single-task Performance

Before examining any between-group differences on dual-task performance, the performance of the groups under single-task conditions must be shown to be comparable.

CL. Figure 6 shows single-task performance for each of the three groups on Days 1 through 4 on the CL task. These data violate the homogeneity of variance assumption ($F_{max_{54,2}} = 3708.277$, $p < .01$) and no standard transformation (log x, log (x+1), 1/x, and $\sqrt{x}$) would meet the assumption. A close examination of the data revealed that much of the violation was caused by performance on the first trial. This trial subsequently was omitted and the remaining data transformed using $Y = \log(x+1)$ ($F_{max_{51,2}} = 445.043$, $p > .01$). The main effect of trial ($F_{16,128} = 63.2591$, $p < .001$) and the group by trial interaction ($F_{32,128} = 1.9991$, $p < .01$) were significant. The main effect of group was not significant ($F_{2,8} = 2.4633$, $p > .14$).

The significant interaction, as depicted in Figure 6, appears to be caused by the poor initial performance of the Alternating Group. Because subsequent individual differences analyses will not use Day 1 data, the data for Trials 1 through 6 which occurred on Day 1 were deleted and the

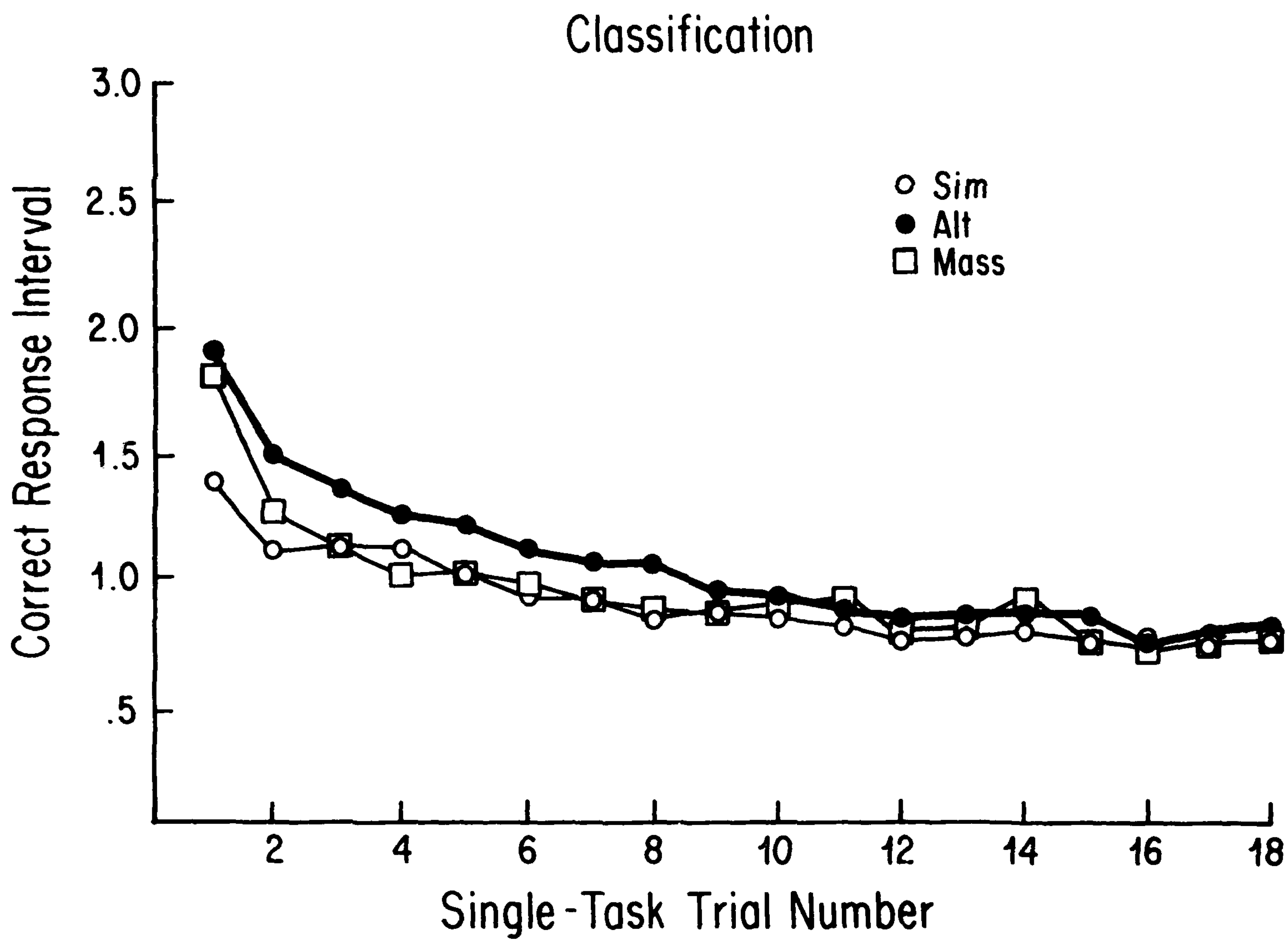

Figure 6. The correct response interval (CRI) for the classification task as a function of response strategy group on Days 1 through 4.

analysis was rerun. The load by trial interaction was not significant in this analysis ($F_{22,88} = 1.4656$, $p > .10$) indicating that between-group differences were confined to Day 1.

ME. An examination of the raw ME data (see Figure 7) indicated a large violation of homogeneity of variance ($F_{max_{54,2}} = 1687.257$) which none of the standard transformations ($\log x$, $\log(x+1)$, $1/x$, $\sqrt{x}$, or x^2) could correct. A close examination of the data revealed that the majority of the effect was caused by one cell; on the eighth single-task trial, the Alternating Response Group had an unusually small variance. Subsequently, this trial was eliminated for all three groups and the standard transformations were attempted to meet the homogeneity assumption. The $\log(x+1)$ transform met the assumption ($F_{max_{51,2}} = 232.660$, $p > .01$) and a two-way repeated measures ANOVA was performed. Neither the main effect of group ($F_{2,8} = 2.0766$, $p > .188$) nor the group by trials interaction was significant ($F_{32,128} = 1.0148$, $p > .457$) . However, the main effect of trials was significant ($F_{16,128} = 20.8575$, $p < .001$) .

TR. A preliminary analysis of single-task tracking showed no significant difference between left- and right-hand tracking performance ($p > .05$) . Therefore, performance on successive left- and right-hand trials was averaged to obtain one score. The performance of the three groups as a function of practice is shown in Figure 8. A two-way repeated measures (group by trials) ANOVA was conducted on the average scores. The main effect of trials was significant ($F_{13,104} = 13.1811$, $p < .001$) . The trials by group interaction also was significant ($F_{26,104} = 2.7220$, $p < .001$) although the main effect of the group was not ($F_{2,8} = 0.4398$, $p > .659$) .

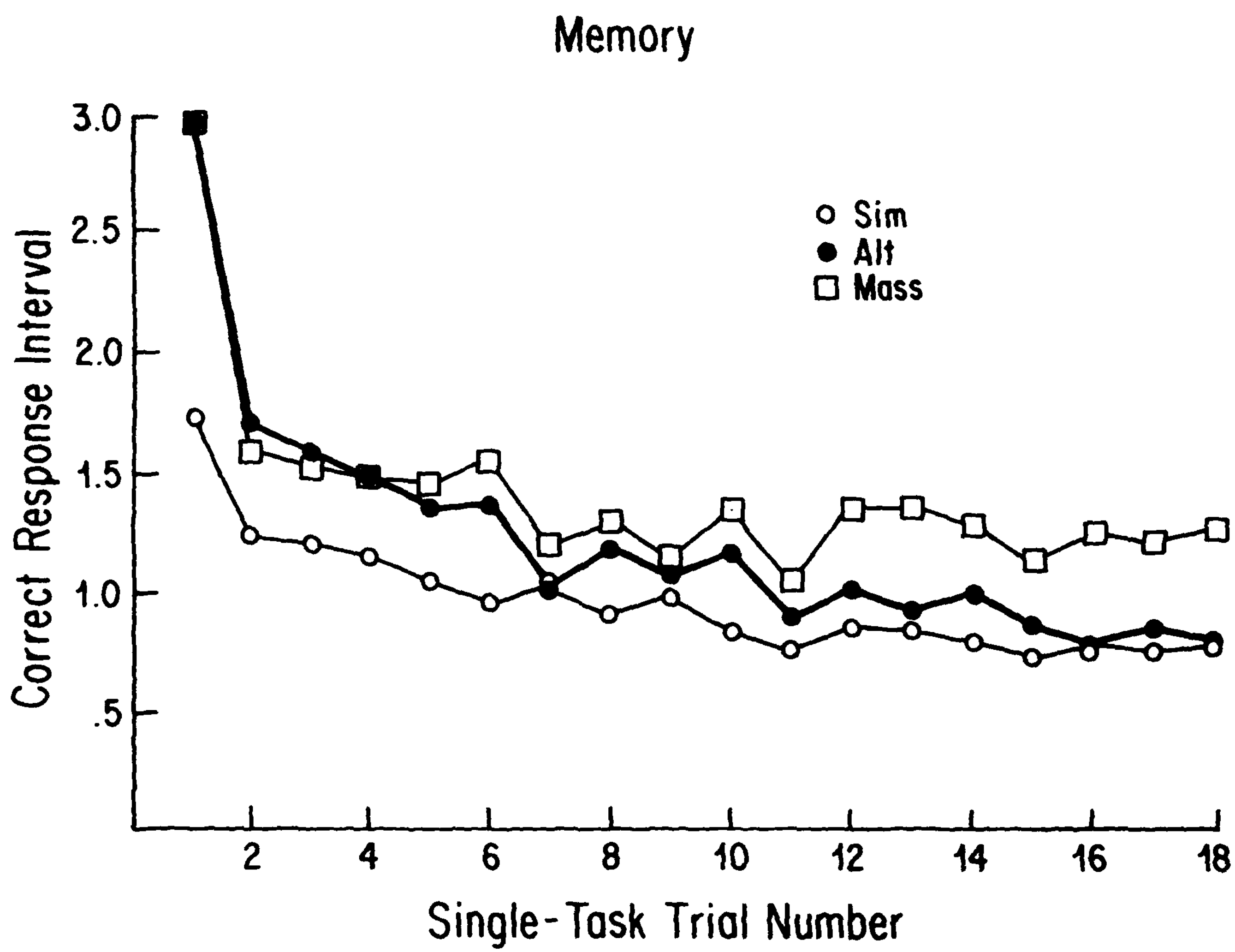

Figure 7. The correct response interval (CRI) for the memory task as a function of practice on Days 1 through 4 and response strategy group.

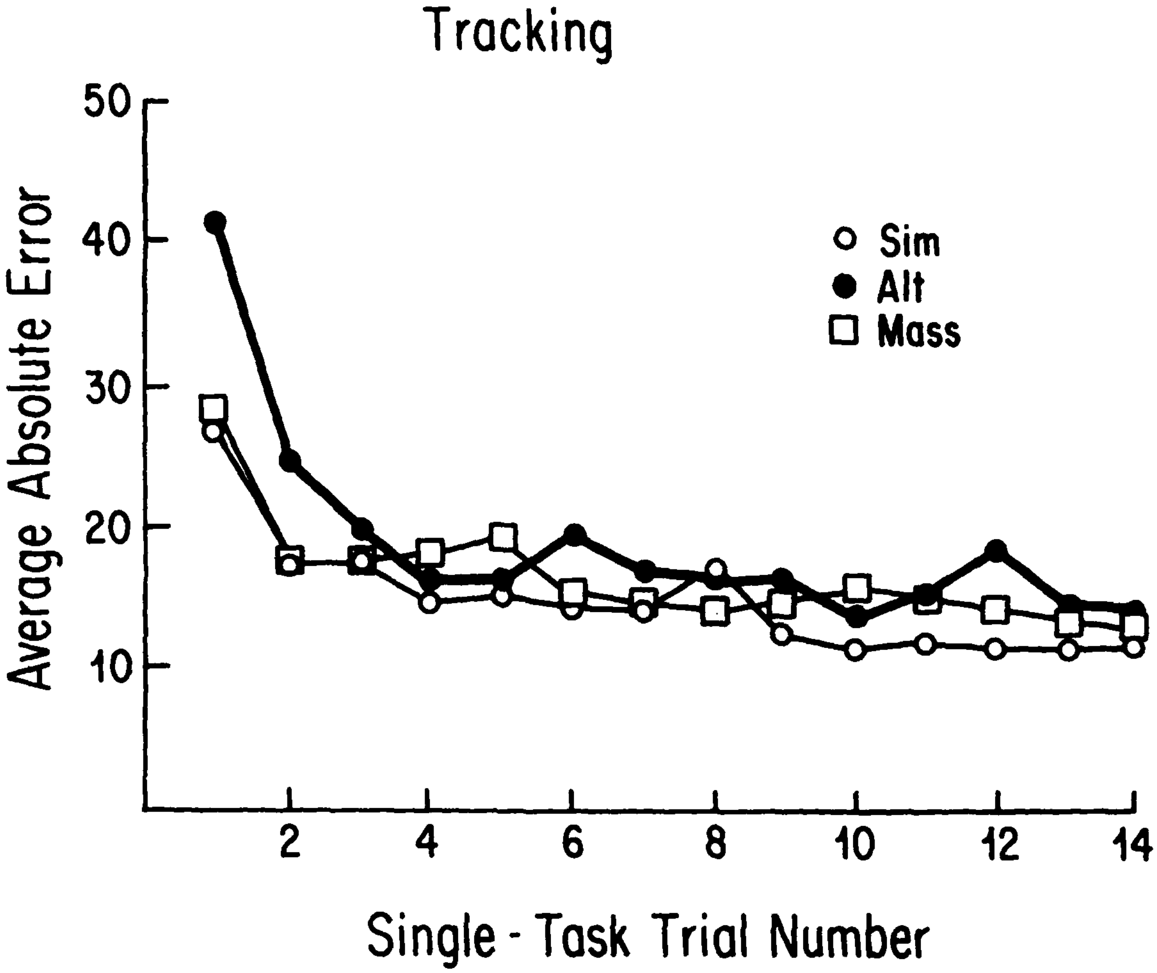

Figure 8. Average absolute error for the tracking task as a function of response strategy group on Days 1 through 4.

Figure 8 indicates that the significant interaction between trials and groups may be attributed to the poor initial performance of the Alternating Strategy Group; performance after Trial 3 is quite similar for all three groups. To test this hypothesis, the analysis was rerun without the first two trials and the interaction was not significant ($F_{22,88} = 1.4405$, $p > .11$) . Thus, the significant interaction should have no practical effect on the individual differences analysis because these analyses only include data after Trial 5.

Selective listening. Although selective listening is not the single-task counterpart of dichotic listening, it was examined to determine if there were any individual differences in a listening task which did not require timesharing skills. To obtain a selective listening score on Day 1, P(A) (the area under the ROC curve) was calculated on each of the two blocks of six trials. These two scores were then averaged. On Days 2, 3, and 4, one P(A) was calculated for each pair of selective trials (one pair preceded the two dichotic listening blocks, one was between, and one followed). These three values then were averaged. Because these scores did not violate the homogeneity of variance assumption ($p > .05$) , a two-way repeated measures ANOVA was conducted on the data. The main effect of trials was reliable ($F_{3,24} = 11.8792$, $p < .001$) . Both the main effect of group ($F_{2,8} = 3.8613$, $p < .067$) and the group by trials interaction were not significant ($F_{6,24} = 1.9030$, $p < .122$) .

Consistent Individual Differences

Differential stability. Before the dual-task data were analyzed for individual differences, the data were examined for stability using a technique suggested by Jones, Kennedy, and Bittner (1979) which is based on Lawley's χ^2 . This statistic tests the assumption that all correlations are equal. When used to test stability, a significant χ^2 implies that all correlations are not equal. That is, the intertrial correlation matrix has not reached stability.

To use this technique, the experimenter first estimates visually where the simplex structure of the intertrial correlation matrix ceases, say after row j , and then performs the χ^2 test on the submatrix formed by rows j through n and columns j through n . If the χ^2 is not significant, implying that performance after the j^{th} trial is stable, then the $(j-1)$ through n submatrix is examined. If this also is not significant, then the $(j-2)$ through n submatrix is examined etc. until the χ^2 test becomes significant, say after including row $(j-i)$. Thus, performance is stable on the $(j-i+1)^{th}$ trial and unstable preceding that point.

A preliminary analysis of the dual-task ME-CL data revealed no significant ($p > .05$) between-task differences. Therefore, performance was averaged over tasks in each trial to obtain one dual-task score. These scores then were analyzed using the te ique described above. Performance was found to stabilize after Trial 14.

A similar analysis was conducted on the TR-TR data. Again, a preliminary analysis indicated no significant ($p > .05$) differences between hands and the dual-task data were averaged over hands to obtain one dual-task score per trial. The technique described above showed that stability occurred after Trial 18.

Stability tests conducted on P(A) scores (two per day for Days 2, 3, and 4) indicated that differential stability was obtained in the first block of trials.

Correction for baseline. Before any analyses were performed, dual-task performance measures were corrected for individual differences in single-task performance using the approach discussed in the Experimental Rationale Section. Performance scores for the left- and right- hand tasks for both the TR-TR and the ME-CL combinations then were averaged to obtain one dual-task difference score. Some misgivings were expressed previously about the appropriateness of selective listing as the single-task counterpart of dichotic listening. Therefore, the dichotic P(A) scores were not adjusted. The means for each group on each combination as a function of practice can be seen in Table 2. It should be noted that for the ME-CL and the TR-TR combinations a high score represents poor performance while a high score on the dichotic listening task represents good performance.

Covariates. The Purdue Pegboard Test was administered during Day 1 as a possible covariate for subsequent analyses. However, the correlation between each of the three Pegboard Tests (left hand alone, right hand alone, and both hands) and the six difference scores described above was uniformly low. Therefore, none of the Purdue Pegboard Test scores was used in the following analysis.

Multivariate analysis. The unadjusted dichotic P(A) scores and the difference scores for the other two task combinations were submitted to a two-way (groups, practice) repeated measures MANOVA. Only two levels of the practice factor, Days 3 and 4, were included in the analysis because neither the TR-TR combination nor the ME-CL combination obtained stability on Day 2. The intercorrelation of these scores is shown in Table 3. The multivariate F for the effect of groups was significant ($F_{6,12} = 4.0860$,

TABLE 2

Dual-task Performance as a Function of Practice and Response Strategy Group

Group	Day 3			Day 4		
	TR-TR	ME-CL	DI	TR-TR	ME-CL	DI
Simultaneous	433	5.9	.846	383	8.2	.850
Alternating	332	10.4	.787	267	13.5	.773
Massed	405	10.6	.855	376	14.7	.862

Note: Performance scores are adjusted for the single-task baseline for the TR-TR and ME-CL combinations only. For these two combinations, the difference scores have been summed over stabilized trials. The dependent variable for the TR-TR combinations is average absolute error; for the ME-CL combinations, correct response interval; and for dichotic listening, P(A) .

TABLE 3

Intertask Correlations on Days 3 and 4

	Day 3			Day 4		
	TR-TR	ME-CL	DI	TR-TR	ME-CL	DI
Day 3						
TR-TR						
ME-CL	-.237					
DI	.211	-.441				
Day 4						
TR-TR	.860**	-.029	.039			
ME-CL	-.139	.964**	-.365	.051		
DI	.358	-.400	.846**	.218	-.357	

Note: The correlations were calculated on dual-task ME-CL and TR-TR data that were adjusted for the single-task baseline and summed over stabilized trials.

** $p < .01$

$p < .02$) . Only the univariate test of P(A) was significant ($F_{2,8}$ = 7.3671, $p < .02$) although the test for the ME-CL combination just missed significance ($F_{2,8}$ = 3.8964, $p < .067$) . The main effect of practice also was significant ($F_{3,6}$ = 17.7950, $p < .01$) . Both the univariate tests on the TR-TR combination ($F_{1,8}$ = 8.4878, $p < .02$) and on the ME-CL combination ($F_{1,8}$ = 54.6367, $p < .001$) were significant. The group by practice interaction was not significant ($F_{6,12}$ = 0.6751, $p > .05$) .

DISCUSSION

This experiment examined performance on three difference task combinations for evidence of consistent individual differences. Only stabilized dual-task performance data were used and individual differences in single-task performance were taken into account by analyzing the difference between single- and dual-task performance. Additionally, each of the three combinations was examined for the development of timesharing skills. Two of the three combinations showed strong evidence for the development of these skills. However, one, dichotic listening, could not be analyzed in exactly the same fashion as the other two and inferences concerning the development of these skills had to be made based on other trends in the data. Although these trends do seem to indicate that some timesharing skills were learned in dichotic listening, other interpretations are possible.

It is necessary, therefore, to reassess the between-group differences without the dichotic data. The same MANOVA performed just on the TR-TR and ME-CL data showed a significant effect of practice ($F_{2,7} = 31.1346$, $p < .001$) with significant univariate tests of both TR-TR ($F_{1,8} = 8.4878$, $p < .02$) and the ME-CL combination ($F_{1,8} = 54.6367$, $p < .001$). The main effect of group ($F_{4,14} = 2.5301$, $p = .0874$) and the group by trials interaction ($F_{4,14} = 0.8018$, $p < .54$) were not significant. Although the main effect of group does not meet the normally accepted levels of statistical significance, in a study such as this one with only 11 subjects the obtained probability level should be regarded as encouraging and as grounds for further research.

Subsequently, it becomes of major concern to determine the basis for the between-group differences. One possible explanation is a speed-accuracy trade-off; under dual-task conditions one group may respond more quickly though less accurately than another. Performance on the ME-CL combination was examined first because such a trade-off would be easy to detect. As shown in Table 4, there is no consistent between-group difference on e CL task although the Simultaneous Response Group does have a consistently lower percentage of error on the ME task. However, because this group also has the fastest reaction times, there is no speed-accuracy trade-off that could account for the between-group performance differences.

Another possible explanation is that the group differences are related to one or more of the major task combination characteristics given in Table 1. A search for the cause of these differences can be simplified temporarily by considering only the Simultaneous and Alternating Response Groups because their performance patterns were exactly the opposite of each other. That is, the Simultaneous Group performed poorly on the TR-TR combination and well on both dichotic listening and the ME-CL combination while the pattern for the Alternating Group was exactly the reverse. It is necessary, therefore, to find one or more dimensions on which the ME-CL combination and dichotic listening are alike but different from the TR-TR combination. Table 1 indicates that there are two dimensions meeting this requirement: the nature of the response (discrete versus continuous) and the type of processing (spatial versus verbal). If the nature of the response were the determining dimension, performance on the two-hand version of the Purdue Pegboard Test should be higher for the Simultaneous Group than for

TABLE 4

Percentage of Error on the Memory-Classification Combination as a Function of Practice, Group, and Task.

Group	Day Number 2	Day Number 3	Day Number 4
Classification Task			
Simultaneous	1.71	1.60	1.57
Alternating	3.33	1.47	0.87
Massed	2.38	1.44	2.56
Memory Task			
Simultaneous	7.78	4.25	3.57
Alternating	10.83	5.58	4.37
Massed	10.69	7.51	4.52

the Alternating Group. However, the average score for the two groups was identical. This result and the fact that the Simultaneous Group appeared to have slightly better single-task tracking than the Alternating Group indicate that the type of response is not the source of the between-group differences.

The data then were examined for evidence that the type of processing was the source of the observed differences. For right-handed males verbal processing should be conducted in the left hemisphere and spatial processing in the right (Dimond and Beaumont, 1974; Kimura and Durnford, 1974; Springer, 1977). There should be little evidence of bilateralization of function although some individual differences in the degree to which the hemispheres are laterally differentiated has been noted. Levy and Reid (1978) state that when left-hemisphere functions invade the right hemisphere, right-hemisphere functions tend to be defective relative to left-hemisphere functions and vice versa. Thus, the between-group differences in performance might be explained if the response strategy groups differed in terms of cerebral lateralization.

The difference in the number of targets detected in the left versus right ear under dichotic conditions is sometimes used as a measure of cerebral lateralization (Berlin, 1977; Inglis, 1968; Pizzamiglio, DePascalis, and Vignoti, 1974; Thomas and Campos, 1978). Because verbal processing usually occurs in the left hemisphere for right-handed males, more right-ear than left-ear targets should be detected (Millay, Roeser, and Godfrey, 1977). If, however, more left-ear targets are detected, then some verbal processing may be occurring in the right hemisphere and less cerebral lateralization may be assumed. The dichotic listening data were analyzed to determine the number of targets detected on each ear for each subject who then was classified as left-ear dominant, right-ear dominant, or neutral. Only the Alternating Response Group showed a consistent pattern: all subjects were right-ear dominant.

Because this finding could indicate differences in lateralization, it was decided to test the subjects' cerebral lateralization more extensively. Thomas and Campos (1978) have demonstrated that lateralization may be related to the degree of handedness; the stronger the preference for a hand, the more lateralized the cerebral functioning. Therefore, a questionnaire and a number of simple motor tasks similar to those of Thomas and Campos (1968) were developed.

Ten of the 11 subjects were contacted and agreed to be tested. Each subject first completed a questionnaire asking him which hand or hands he used to perform certain common acts, such as drawing or using a toothbrush. He also was asked to indicate which hand his parents and siblings use to write. Next, each subject was observed while he wrote three dictated sentences to determine if he used the inverted hand posture that may indicate ipsilateral motor control (Levy and Reid, 1978). Finally, he performed five motor tests as tests of cerebral lateralization. The first required the subject to screw six nuts on a bolt. For the second he depressed a response key as rapidly as possible during a 30-sec period. The third was the single-[illegible] rsion of the Purdue Pegboard Test. The fourth tested the grip strength of each hand using a dynamometer. The last required the subject to balance a .76 m dowel on his index finger as long as possible.

The subject was asked to begin each test with the hand with which he felt he could perform best. The subject performed each test four times, alternating between his left and right hands. The performance on each hand was averaged and the test was given a score of +1 if the subject performed better with his right hand and -1 if he performed better with his left. Each test was also given a +1 if the subject began with his right hand and a -1 if he began with his left. Thus, the highest possible score for right handedness on the five motor tests was +10. For the questionnaire a score for +1 was given for each "right hand" answer, a score of 0 for "both" answer and a score of -1 for a "left hand" answer. The familial handedness part of the questionnaire was not scored.

None of the subjects tested used the inverted writing position. The range of scores on the written questionnaire was +10 to +15 with no apparent group differences. However, the scores on the motor tasks ranged from +2 to +10 and did show obvious group differences. The average score for the Alternating Group was 9.3; for the Massed Group (two subjects only), 8.0; and for the Simultaneous Group, 5.8. The corresponding within-group variances were 0.89, 0.0, and 7.36 respectively. These results imply that lateralization is related to response strategy and to multiple-, but not single-, task performance, but it is not immediately evident why the three response strategy groups should produce the pattern of results seen in Table 2.

A tentative explanation of these results rests on one of the more recent theories of attention, the Structure Specific Resources Theory (McLeod, 1977; Navon and Gopher, 1979; Wickens, Mountford, and Schreiner, 1979). Briefly, the Structure Specific Resources Theory maintains that attention does not reside in a single general pool as suggested by

Kahneman (1973) but is allocated to a number of smaller more specific pools, each with its own capacity. These pools have been associated with input and output modalities (Wickens, 1979), cerebral hemispheres (Dimond and Beaumont, 1974; Friedman and Polson, 1980; Kinsbourne and Hicks, 1978), and stages of processing (Israel, Wickens, and Donchin, 1979; Wickens, 1979). The fundamental assumption of this theory is that resources cannot be shared between pools. For instance, if the capacity of a pool associated with one input modality is exceeded, causing a decrement in performance, idle capacity associated with the resource pool of an unused input modality could not be reallocated to the first pool.

If the two hemispheres represent two separate pools of resources (see Friedman and Polson, 1980 for an in-depth review) and subjects who employ different response strategies have different degrees of lateralization, then a tentative explanation of the results may be made as follows. The subjects in the Alternating Response Group are the most lateralized as indicated by their performance on the dichotic listening task and the motor tests. Therefore, they may have all of their verbal processing capacity in the left hemisphere and the spatial capacity in the right. The subjects in the Simultaneous Response Group, who are much less lateralized, may have some of the verbal processing capacity on the right hemisphere as well as in the left. Thus, using Levy and Reid's reasoning, the Simultaneous Response Group may perform the TR-TR combination less well than the Alternating Response Group because they have less spatial information processing capacity available to be used in the task. However, they perform the dichotic listening task and the ME-CL task better than the Alternating Group because they have more total verbal processing capacity available.

The performance of the Massed Strategy Group is more difficult to interpret in terms of laterality; they performed only one left-hemisphere task well. However, it may be that this is not a homogeneous group; in the Strategy Analysis Section it was noted that two of the subjects used mixed strategies rather than a pure massed strategy.

In summary, it should be noted that, like the studies discussed in the Literature Review, this experiment provides no evidence for a general time-sharing ability. It does, however, provide evidence for consistent individual differences that could be used for selecting operators for complex systems and in designing equipment. Although one possible explanation for these differences is differential cerebral lateralization, more research must be conducted to test this hypothesis.

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APPENDIX A

SINGLE-TASK TRACKING INSTRUCTIONS

On the display in front of you, you will see a tracking task that looks like this (show Figure A). You are to keep the two small bars centered on the line. To do this, you must move the control stick either to the left or the right. If you want the circle to move to the right, move the stick to the right. If you want the circle to move to the left, move the stick to the left.

The distance between the center of the bars and the vertical line is the error. At the end of each trial your average error will be displayed so you can see how well you are doing. The display will look like this (Figure B). On each trial you are to try to beat your performance on the preceding trial.

All trials in this experiment will be 1 min long. There will be a 1-min break between trials. A buzzer will sound before each trial. The trial will start 3 sec after the buzzer stops. The intercom will be on throughout the experiment, so you can communicate with me at any time.

Are there any questions?

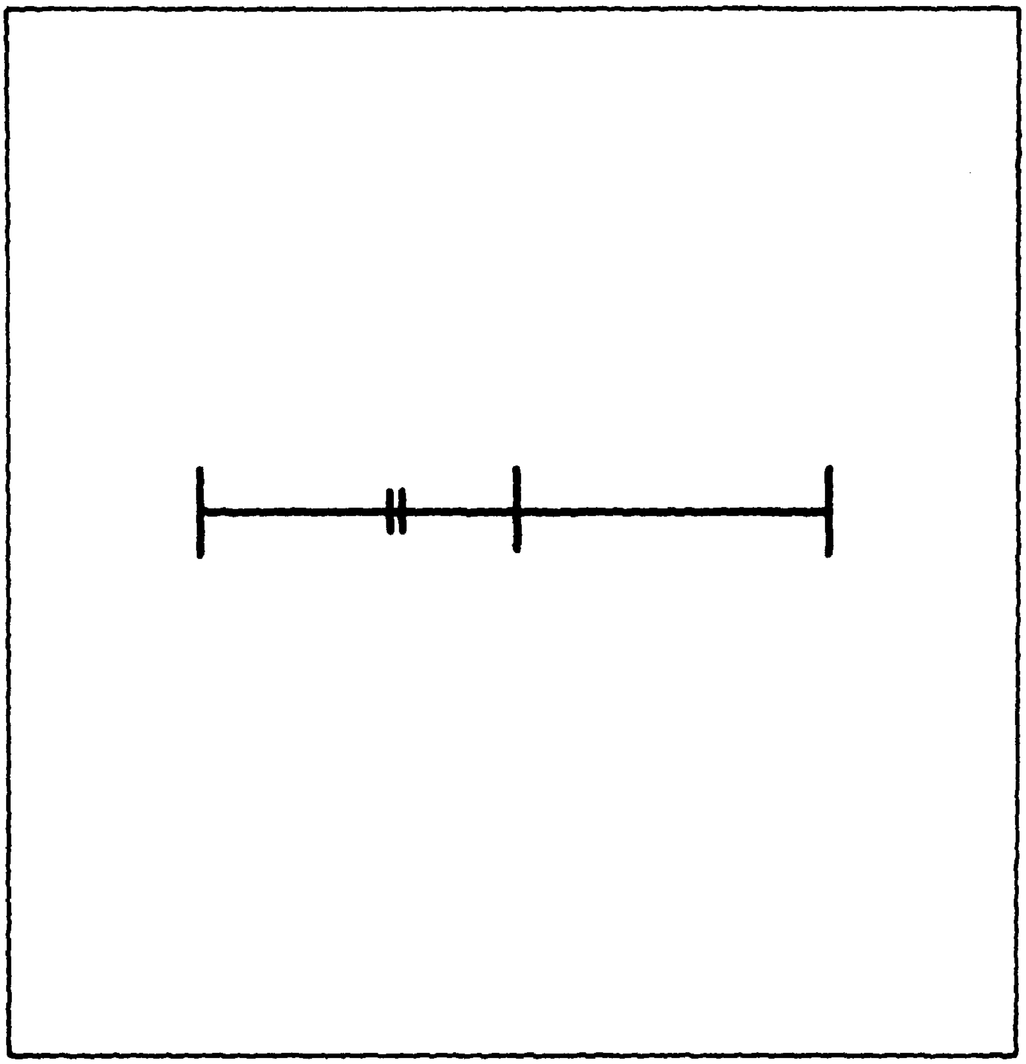

Figure A. The single-task tracking display.

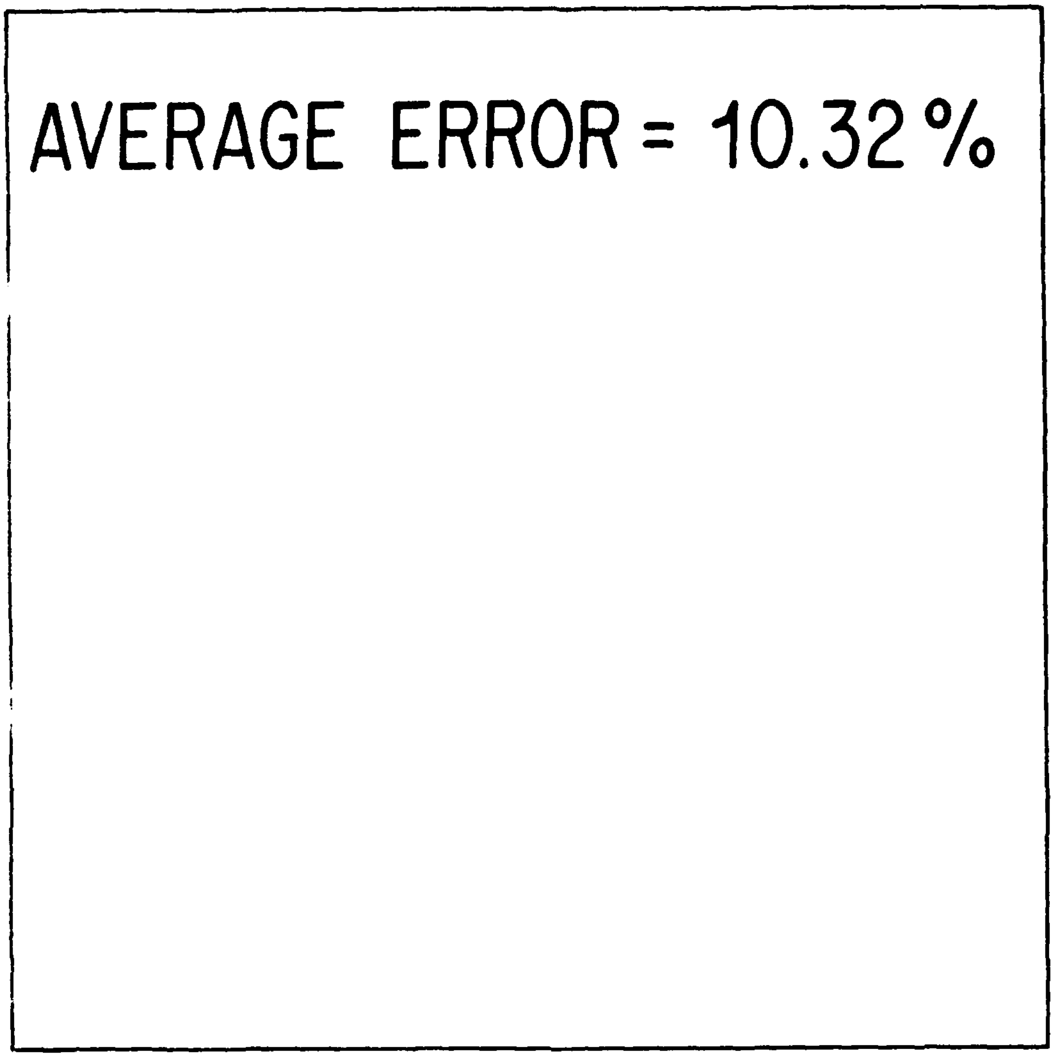

Figure B. An example of the single-task tracking feedback display.

APPENDIX B

SELECTIVE LISTENING TASK INSTRUCTIONS

The task you will perform is a selective listening task. Your job is to detect letters in a series of numbers when a distracting background noise is present. During each trial the numbers and letters will be presented to both ears at the same time. However, you will direct your attention to only one ear at a time. At the beginning of each trial you will be told by the experimenter which ear you will concentrate on in the upcoming trial. Whenever you hear a letter, push the #4 key on the keyboard corresponding to the ear where you heard the letter. For instance, if you heard the letter in the left ear, you would press the #4 key on the left-hand keyboard. If you heard the letter in the right ear, you would press the #4 key on the right-hand keyboard. You will respond only to letters in the ear on which you are concentrating. When you detect a target, respond as quickly as you can. You may guess if you are not completely certain you heard a target. Please only press the keys when responding to a letter. Do not press the keys at any time between trials.

Not all of the letters of the alphabet are present on the tape. The letters W,J,H,I, and T are never used. Only numbers between 0 and 9 are used. Letters will appear on each channel and may appear on both channels simultaneously.

Each trial will last approximately 75 sec. Then you will have a 40-sec rest pause. After the rest pause you will begin another trial. However, in this next trial you will concentrate on the other ear and you will press the #4 key on the other keyboard. Throughout the rest of the experiment your attention will be directed to alternating ears. The background noise will begin about 5 sec before a trial starts to alert you to the beginning of the trial.

During the experiment your progress will be monitored on a television monitor for safety reasons. If for any reason you need to talk to me, press the lever on the intercom to talk and I will be able to hear you. If at any time you feel that you do not wish to participate further in the experiment, you are free to leave. Just inform me that you are no longer interested and want to stop.

Remember, press the #4 button every time you detect a letter. Try to respond as quickly and accurately as possible. Are there any questions?

APPENDIX C

MEMORY TASK INSTRUCTIONS

The task you are to perform is a memory task. You will perform this task with your right hand. Your first finger will correspond to the number 1, the second to the number 2, the third finger to the number 3, and the little finger to the number 4. You are to keep your fingers on the keys at all times. Do not use your thumb to respond.

In this task digits will be presented one at a time. You must remember the digit that is currently being displayed and respond to the preceding digit. As soon as you respond, the current digit will be erased and a new one presented. For instance (show Figure C), suppose the first stimulus is a three. Because there are no preceding stimuli, simply push button one. This is just a signal to the computer that you have seen the first stimulus. It has no relation to the stimulus. After you have seen the second stimulus, a two, press three for the preceding stimulus. After you have seen the third stimulus, a one, press two for the second stimulus, etc. Digits will be erased regardless of whether you hit the correct key or not.

At the end of each trial your performance will be summarized and displayed on the screen. The display will look like this (show Figure D). The ME in the top line identifies the task as the memory task. The CRT is the correct response time. This value represents your average time between correct responses. Any mistakes you make increase this value. The Total Responses indicates the number of responses you made regardless of whether they were right or wrong. The Percent Correct indicates the percentage of correct responses. Your job is to make the CRT as small as possible while

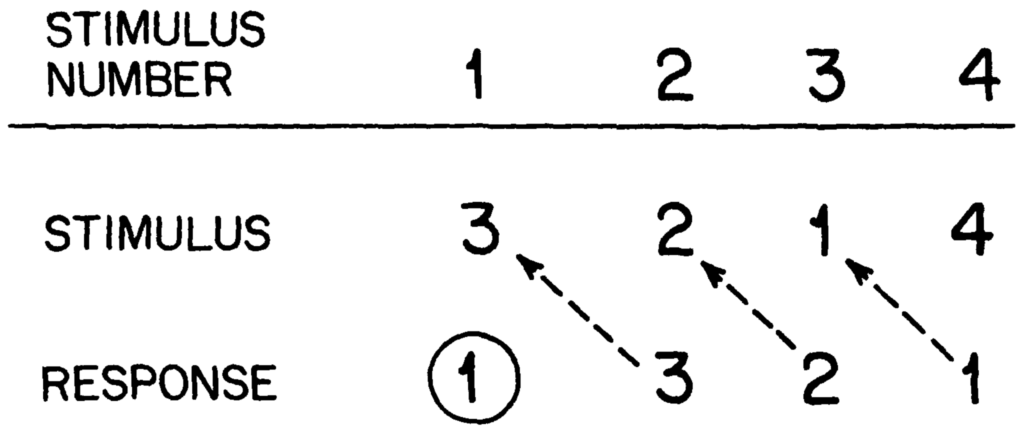

Figure C. A display used to explain the memory task to the subjects.

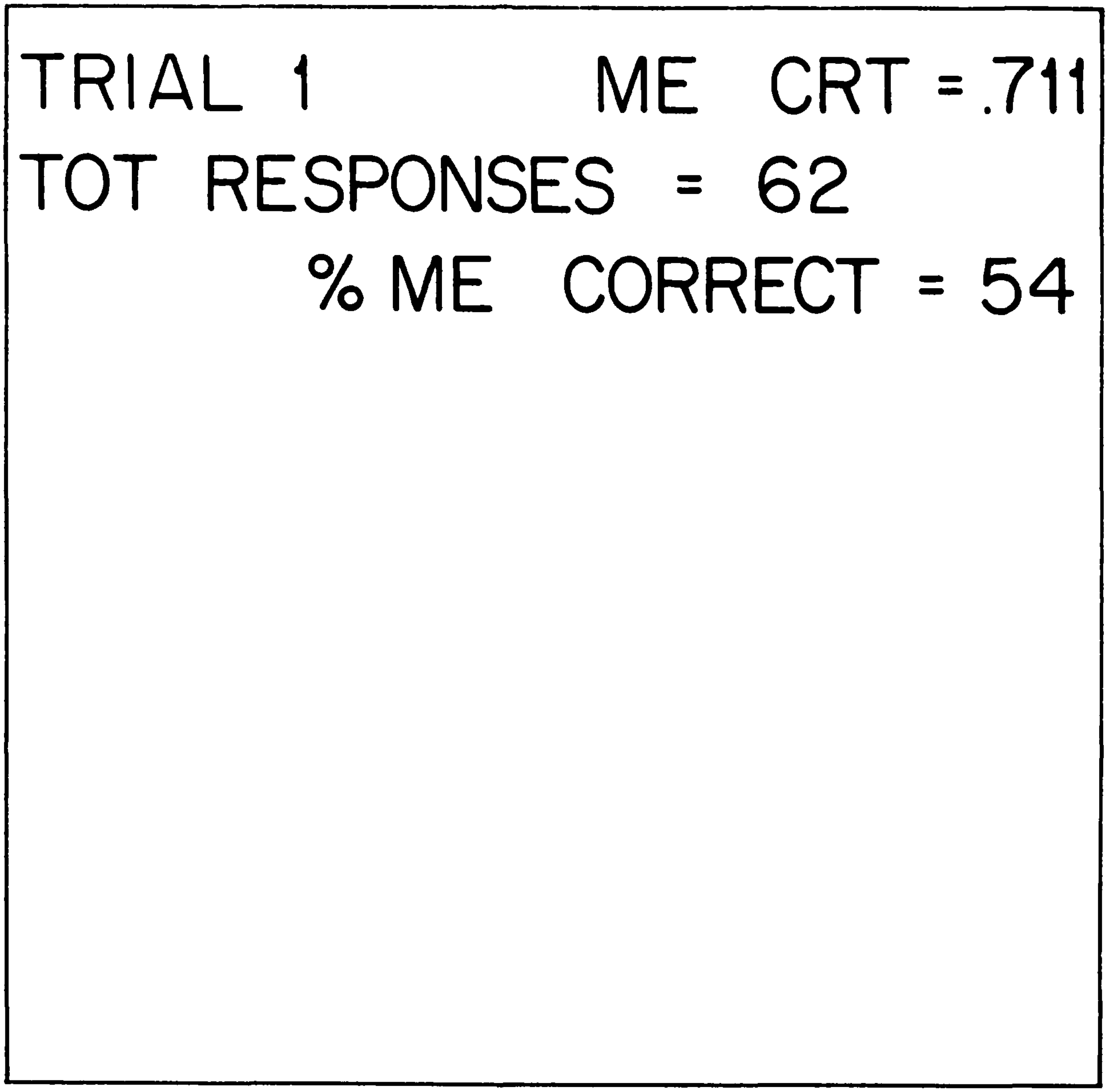

Figure D. An example of the single-task memory feedback display.

maintaining 95% accuracy or better.

Are there any questions?

APPENDIX D

CLASSIFICATION TASK INSTRUCTIONS

The task you are to perform is a classification task. On the display in front of you, you will see two digits side-by-side. The digits may vary on two dimensions: size and name. For example, you may see a small seven and a large six. Sometimes the digits will be alike on both dimensions (such as two small sevens), sometimes on one dimension (such as a large seven and a large six), and sometimes they will be different on both dimensions (such as a small seven and a large six). You are to indicate the number of dimensions on which the stimuli are alike. You will indicate your response using only your left hand. To indicate that they are alike on both dimensions, press the right key with your first finger. To indicate that they are alike on one dimension and different on the other, press the middle key with your second finger. To indicate that they are different on both dimensions, press the left key with your third finger. The pair will be erased from the screen regardless of whether you hit the correct key or not. You are to keep your fingers on the keys at all times. Do not use your thumb to respond.

At the end of each trial your performance will be summarized and displayed on the screen. The display will look like this (show Figure E). The CL in the top line identifies the task as the classification task. The CRT is the correct response time. This value represents your average time between correct responses. Any mistakes you make increase this value. The Total Responses indicates the number of responses you made regardless of whether they were right or wrong. The Percent Correct

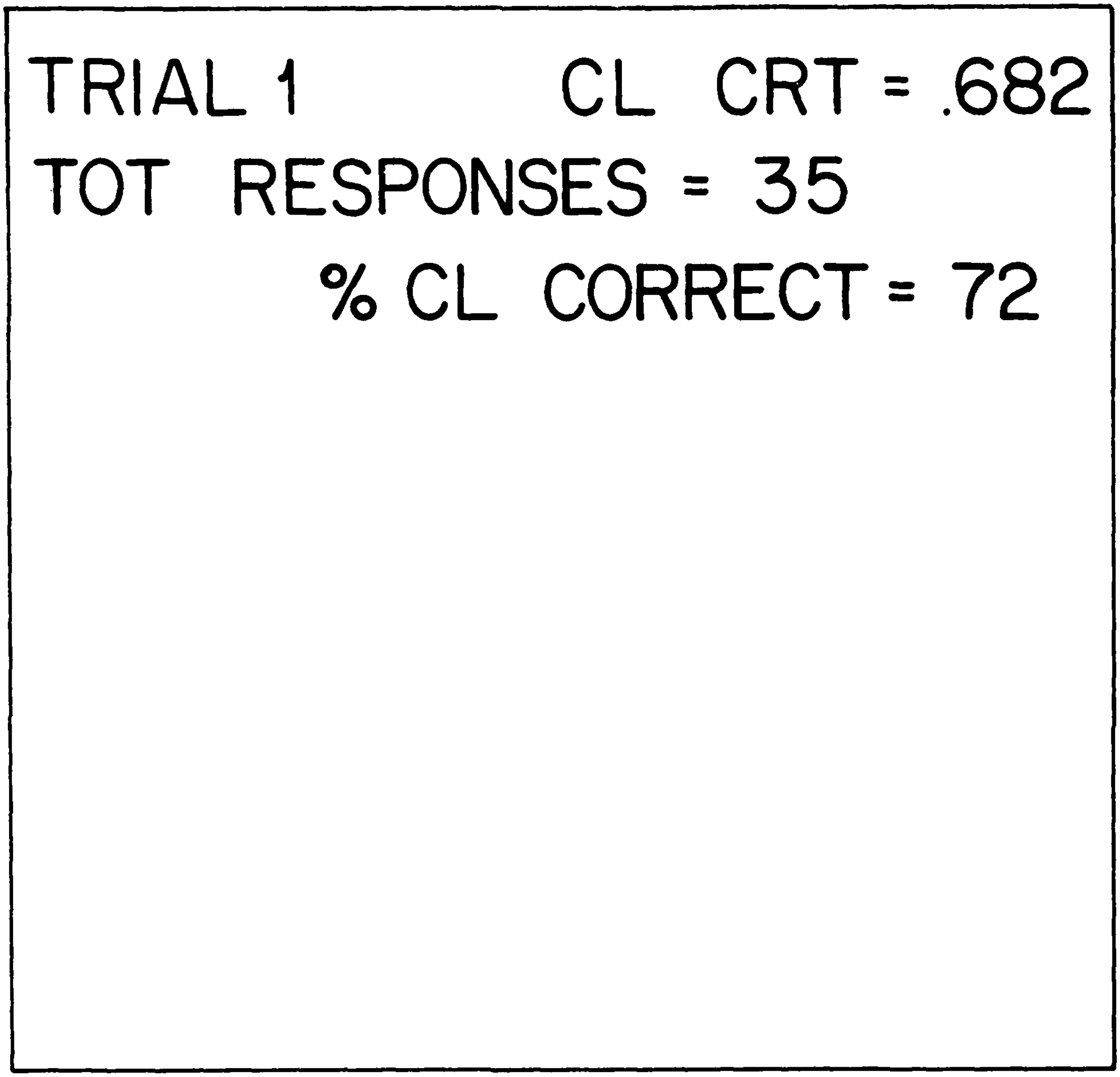

Figure E. An example of the single-task classification feedback display.

indicates the percentage of right responses to the total number of responses. Your job is to make the CRT as small as possible while maintaining 95% accuracy or better.

Are there any questions?

APPENDIX E

DICHOTIC LISTENING INSTRUCTIONS

The task you will perform today is a dichotic listening task. Again, your job is to detect letters in a series of numbers when a distracting background noise is present. Today the numbers and letters will be presented to both ears at the same time. However, you will give equal attention to both ears. Whenever you hear a letter, push the #4 key on the keyboard corresponding to the ear where you heard the letter. For instance, if you heard the letter in the right ear, you would press the #4 key on the right-hand keyboard. If you heard the letter in the left ear, you would press the #4 key on the left-hand keyboard. When you detect a target, respond as quickly as you can. You may guess if you are not completely certain you heard a target. Please only press the keys when responding to a letter. Do not press the keys at any time between trials.

Not all of the letters of the alphabet are present on the tape. The letters W,J,H,I, and T are never used. Only numbers between zero and nine are used. Letters will appear on each channel and may appear on both channels simultaneously.

Each trial will last 75 sec. Then you will have a 40-sec rest pause. After the rest pause you will begin another trial. The background noise will begin about 5 sec before a trial starts to alert you to the beginning of a trial. You will first perform a short block of selective channel trials, just as you performed yesterday, followed by a longer block of dual-channel trials. This pattern will be repeated throughout each session over the 3 days. We will take a short break after each block of dual-channel trials. In performing under the dichotic condition, we would like you to give equal attention to both channels and not favor one ear over the other. Please follow this strategy as closely as possible.

During the experiment your progress will be monitored on a television monitor for safety reasons. If for any reason you need to talk to me, press the lever on the intercom to talk and I will be able to hear you. If at any time you feel that you do not wish to participate further in the experiment, you are free to leave. Just inform me that you are no longer interested and want to stop.

Remember, press the #4 button every time you detect a letter. Try to respond as quickly and accurately as possible.

Are there any questions?

APPENDIX F

MEMORY-CLASSIFICATION INSTRUCTIONS

Now you will perform both tasks simultaneously. The memory task will be performed with the right hand; classification, with the left. On the right side of the screen you will see a digit between one and four for the memory task. On the left side of the screen you will see a pair of numbers between five and eight for the classification task. To start the memory task, hit the left key of your right-hand keyboard as you did under single task conditions. The stimuli will be erased from the screen regardless of whether your responses were correct or incorrect. You are to consider the tasks as equally important.

Your job is to respond to the stimuli as quickly and accurately as possible. On each trial you should try to obtain a smaller CRT than on the preceding trial while maintaining 95 % or better accuracy on both tasks. At the end of each trial your CRT, percent accuracy, and total number of responses will be displayed for both tasks on the screen so you can see how well you are doing. The display will look like this (show Figure F). All values will be calculated as in the single-task trials.

Are there any questions?

TRIAL 1 ME CRT =.778

TOT RESPONSES = 66

%ME CORRECT = 98

TRIAL 1 CL CRT =.524

TOT RESPONSES = 53

%CL CORRECT = 92

Figure F. An example of the dual-task memory-classification feedback display.

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